USG

USG Corporation
125 South Franklin Street
Chicago, IL 60606-4678
312 606-4000
Fax: 312 606-4484

Founded in 1902

May 10, 2006

Dr. Scott A. Masten
Director, Office of Chemical Nomination
and Selection
NIEHS/NTP
111 T. W. Alexander Drive
P.O. Box 12233
Research Triangle Park, NC 27709

Dear Dr. Masten:

United States Gypsum Company has been manufacturing and selling gypsum products for over 100 years. United States Gypsum Company is a subsidiary of USG Corporation. USG has over 20 gypsum production facilities in the United States. USG supplies its customers with SHEETROCK® Brand Gypsum Panels, SHEETROCK® Brand Joint Compounds, building plasters, industrial plasters, agricultural gypsum, industrial gypsum, and food and pharmaceutical grade gypsums.

The attached information is provided for evaluation and review in consideration of nominating gypsum to the NTP Testing Program. This input is intended to fill significant gaps in the knowledge of gypsum toxicity and to enhance your predictive ability on determining and prioritizing the need to conduct further studies. The information provided addresses gypsum biosolubility, intratracheal and inhalation studies, reproductive and teratological effects, genotoxicity studies, carcinogenicity, and worker exposures to gypsum dust.

USG has retained the services of R. P. Musselman, Inc. to assess the safety of gypsum. Much information has been obtained in the short amount of time since the NTP notification was published in the Federal Register, April 11, 2006. Additional published literature is available but could not be obtained and translated into English given the time constraint of the comment period. The attached Safety Assessment of Gypsum Dusts provides significant information about gypsum on human exposures, animal studies (inhalation, intratracheal, intraperitoneal), gypsum fiber solubility, mutagenicity, cell toxicity, and carcinogenicity (See Attachment A).

WTC Dust

What individuals were exposed to after the World Trade Center (WTC) collapse should be a concern. Dust, smoke, fumes, and volatiles should be examined to aid in determining causes of any long-term health effects. Dust around the WTC collapse would be expected to contain gypsum since gypsum wallboard was a common wall panel used during the construction of the buildings. Natural gypsum was used to make gypsum wallboard at the time of the WTC construction. It should be noted that the pH of WTC dust has been reported in the alkaline range of 9-11 and that of natural gypsum (all phases including anhydrite and gypsum hemihydrate) would be in the pH range of 7-7.5. Elevated pH levels of WTC dust might be due to calcium bearing mineral phases in the buildings being converted to calcium oxide (lime). Conversion to lime (pH > 12) could have resulted from exposure to the extreme temperatures generated by the event. The presence of a very small amount of lime in any dust mixture could increase the pH of the dust significantly. This is an example of just one parameter of many that distinguishes gypsum dust from WTC dust and exposures to dusts in other occupations.

USG workers are exposed to some amount of gypsum dust every work day. Exposures are typically well below OSHA PEL and ACGIH TLV levels but even with the use of engineered dust controls, the work environment is not totally dust free. Analysis of latent dust in the plant and industrial hygiene sampling shows the dust is commonly composed of gypsum fibers. USG workers do not display any symptoms of health effects and none are observed similar to those described attributed to the dust from the burning and collapse of the World Trade Center.

Information Relating to Oral Exposure to Gypsum and Medical Applications
Oral, medical, and dental applications of gypsum were generally not included in the NTP review. It is recognized that these applications would not be the same exposure of gypsum as exposures in occupations. However, in considering gypsum health effects, it can be useful to review studies conducted in these applications that can provide significant information on behavior of gypsum in humans. For example, the Food and Drug Research Laboratories, Inc. in 1974 reported no discernible effects or difference in abnormalities in their teratologic evaluation of calcium sulfate in mice, rats, and rabbits (See Attachment B).

Also, there have been numerous studies using gypsum for bone reconstruction and no tumors or carcinomas have been reported in animals or humans. Studies in the medical field show gypsum did not have adverse effects on human tissue or organs. Turner et al., 2001 (See Attachment C) summarized many years of radiographic and histologic assessments of calcium sulfate in experimental animal models and human clinical uses. It is recognized that medical grade gypsum is a purified form of gypsum but nonetheless the information on the behavior of gypsum in humans can be evaluated and used to help predict what could happen when one is exposed to gypsum dust.

Gypsum in Indoor Environments
USG is very interested in the composition of indoor air environments. In addition to the studies referenced in the NTP review pertaining to gypsum in indoor environments, there are airborne fiber studies available in the literature. The additional information provides a better characterization and understanding about fibrous gypsum dust concentrations in buildings. Like many environments, there could be a wide range of airborne fiber concentrations indoors depending upon the building activities and conditions at any given time.

The 1994 German study referenced in the NTP Review Document for fibrous dusts indoors reported the average concentration of gypsum fibers at 0.003 fiber/cm^3. This fiber concentration appears low when compared to the NIOSH REL, OSHA PEL, and ACGIH TLV fiber concentration limit for asbestos of 0.1 fiber/cm^3 and considering the biosolubility and health effects of gypsum.

Most of the products manufactured by USG goes into indoor environments. A U.S. study on indoor airborne respirable fiber concentrations in commercial and residential buildings showed very low levels ranging from < 0.0001 fiber/cm^3 to 0.029 fiber/cm^3 [Carter, et al., AIHA Journal, 60: 794-800 (1999)]. The airborne fibers were primarily organic (97%) with the total respirable inorganic fibers concentrations reported at < 0.0001 fiber/cm^3. These results are similar to the results of other studies reporting indoor airborne fibers. The lack of gypsum fibers in the indoor environments of typical buildings correlates with the fact that installed gypsum panels do not emit fibrous dust unless the product is disturbed.

Intratracheal Studies

In 1974, USG sponsored a 26-week IT toxicity study of gypsum fibers in rats that was conducted at Hazleton Laboratories, Inc. located in Vienna, VA (See Attachment D1 and additional IT studies on guinea pigs by Dr. George W. Wright discussed in Attachment D2). The purpose of the study was to identify, evaluate, and characterize the effects of a single intratracheal instillation of gypsum fibers into the lung of male rats at levels of 0.1 mg, 1.0 mg, and 10.0 mg. Animals were sacrificed at intervals of 24 hours, 1 week, 4 weeks, 13 weeks, and a terminal sacrifice was made at 26 weeks. This report concluded by stating "histomorphological alterations attributable to the test material were not apparent at any of the dosage levels at any of the time intervals".

A German study by Bartmann, 1986 (See Attachment E) is another long-term intratracheal study using rats. The results of this study showed no adverse respiratory effects. Gypsum fibers were not present after 24 hours of the instillation.

Mutagenicity Studies

A published Finnish study by Simonen, 1991 on FGD gypsum was translated into English and is provided in Attachment F. Simonen observed no mutagenic effects in the Ames test using FGD gypsum.

Health Effects from Occupational Exposures

USG does have information on occupational exposures to gypsum that is significant. Workers at the United States Gypsum Company manufacturing plants, quarry, and mining operations are exposed to gypsum every work day. In over 100 years of USG operations, there has been no evidence of adverse long-term health effects in workers from exposure to gypsum dust.

Shirley Conibear, M.D., M.P.H., has served as USG's medical consultant for over 25 years. Dr. Conibear designed and implemented a medical surveillance program of USG production workers. Medical monitoring of workers includes pulmonary function testing (PFT), PA chest X-ray read by a B Reader/radiologist, and medical history. Dr. Conibear has not observed "an excess of lung disease, a pattern of X-ray abnormalities indicative of fibrotic changes or a pattern of symptoms suggestive of occupational lung disease". In addition, there has not been an observed pattern of health effects on any other organ systems based on other medical testing conducted as a part of the medical surveillance program (See Attachment G).

As noted in the NTP literature review, the studies regarding a possible association between cancer risk and occupations when exposed to gypsum can be confusing because the occupational studies are confounded with exposures to other toxic materials. Employees at USG production plants are exposed principally to gypsum and not exposed to the same extent to other toxic materials compared to some construction workers.

USG has not observed any decrease in lung function or respiratory symptoms from gypsum exposure at our mines and quarries. However, the quartz content of the gypsum deposits in the U.S. are not close to the higher quartz content in the Nottinhamshire and Sussex mines in England. This may explain the difference of observed lung shadows by Oakes et al., 1982 in their study and why there are no observed abnormalities in lung X-rays of USG workers.

Quarried or Mined Gypsum and FGD Gypsum

Flue Gas Desulfurization (FGD) gypsum has been used to make gypsum wallboard since the early 1990s. Comparison of composition between FGD gypsum and natural gypsum shows little difference between the two (See Attachments A and H). Trace element concentrations contained in FGD gypsum are typically similar to those found in U.S. soils and natural gypsums. Employee exposures to FGD gypsums do not show detrimental health effects. Dr. Conibear has not observed any discernible difference between the medical findings in workers exposed to FGD gypsum versus natural gypsum (See Attachment G).

Regulatory Status

The limits of exposure to gypsum dust established by NIOSH, OSHA, and ACGIH are relatively high based upon the knowledge that gypsum has few health effects. Diseases and chronic health effects have not been detected or observed with gypsum exposures by these organizations or the Center for Disease Control. There has been no observed causal relationship between gypsum and chronic health effects.

Prioritizing Further Studies
There is no evidence from USG medical information that worker exposure to gypsum dust for a working lifetime would cause health-related effects due to reproductive and developmental toxicity, genetic toxicity, immunotoxicity, neurotoxicity, or carcinogenicity.

Based upon all the information available on gypsum, one could predict that gypsum would disappear quickly in any short-term pulmonary toxicity studies with no significant effects.

Sincerely,

Charles D. Byers

Charles D. Byers, Ph.D.
Manager, Product Safety & Industrial
Hygiene

Attachments (9)

ATTACHMENT A

SAFETY ASSESSMENT OF GYPSUM DUSTS

Safety Assessment of Gypsum Dusts

By

Rod Musselman, DrPH

R.P. Musselman, Inc.
One Wren Court
Woodridge, IL 60517
(630) 541 – 3342

For USG Corporation
125 South Franklin Street
Chicago, IL 60606

May 8, 2006

Table of Contents

Review of Safety Assessments of Gypsum Dusts

Executive Summary

Gypsum is abundant in the earth's crust where it has been mined and quarried since ancient times for the manufacture of products for the built environment such as plaster and wallboard. It has many other uses including products for agriculture, horticulture and silviculture, as well as for the food, water treatment, pharmaceutical, pigment and paper industries. Gypsum plasters have many applications in dentistry and medicine including casts and implants.

In the last 15 years gypsum has become available as a byproduct from stack scrubbing at coal-burning utility plants. This form of gypsum, known as flue gas desulfurization (FGD) gypsum is used to make wallboard for the construction industry. FGD gypsum is essentially the same as mined and quarried gypsum in terms of calcium sulfate and trace metal content. FGD gypsum would not be expected in the World Trade Center buildings except perhaps in some renovation projects.

Airborne gypsum particles or fibers are considered to be "nuisance" (not otherwise specified, NOS) dusts in the work environment. High levels of airborne gypsum dust will cause temporary irritation to the eyes, nose and throat, and settled gypsum dust will cause dry skin with prolonged exposure. Gypsum wallboard panels or boards for the construction industry are fabricated such that an individual panel can be cut using the efficient and rapid "score and snap" technique which generates almost no dust. The use of power tools to cut wallboard panels is discouraged and is rarely employed. For those situations where power tools are necessary, local exhaust systems are recommended. Where this is not possible, suitable and approved respirators are recommended. Medical and experimental studies and reports generated over several decades support the safety of gypsum. Food and medical grade gypsum received GRAS (Generally Regarded As Safe) status from the US Food and Drug Administration many years ago. Gypsum particles are not sensitizers and are not considered to possess developmental, reproductive or carcinogenic potential. No chronic or irreversible and progressive diseases have been attributed to gypsum exposures.

Gypsum is soluble in liquids simulating lung fluid, and animal models have demonstrated that inhaled gypsum fibers or gypsum fibers instilled into the lungs of experimental animals dissolved quickly (e.g., within 24 hours) and did not cause any adverse, irreversible effects such as fibrosis. Experimental data from animal intratracheal instillations also indicated that in simultaneous quartz and gypsum instillations, gypsum mitigated the irreversible lesions caused by respirable crystalline silica exposures, possibly because of its buffering capacity.

Clinical studies of gypsum miners and quarry workers attributed quartz exposure as the causative agent responsible for identified silicosis cases. The authors who followed these cases over a period of several years noted that the silicosis did not appear to progress, or that it progressed in individuals at a slower rate than would be expected when compared with silicosis cases identified in coal or hard rock miners .

Additionally, lifetime experimental studies in which billions of long/thin gypsum fibers were injected into the intraperitoneal cavities of rats did not induce tumors, leading the researchers to conclude that gypsum fibers are too soluble and transient in animal tissues to be considered tumorigenic.

The medical and experimental data associated with gypsum exposures have led governmental regulatory bodies to consider gypsum to have no or very, very little capacity to induce cancers in animals or humans. For example, in Germany the MAK – und BAT – Werte – Listse (1993) states that gypsum is "nicht kanzerogen" – not a carcinogen. Similarly, German regulations TRGS 906-1 and TRGS 905 ("Technical Rules for Hazardous Materials," Issue June 1997/Version November, 1997 and Appendix 1, "Third Regulation in order to modify the Regulation on Hazardous Substances," July 25, 1994) contain language by which a fiber can be exonerated as a carcinogen. Paragraph 4 [page 7 of the translation] of the TRGS 905 document specifically notes that gypsum is not considered carcinogenic:

> "(4) Under special circumstances, a classification different from Paragraphs 2 and 3 [Carcinogen Category 2 or 3 classification] can take place if suitable data are presented by the manufacturer of the fibers – for example:
>
> - Data which prove a very low biostability (for example, comparable with gypsum fibers);"

The German regulation as it applies to gypsum was derived from and based on scientific knowledge derived from experimental studies that demonstrated the very soluble nature of gypsum fibers in body fluids and lung tissue, and the lack of disease observed in individuals exposed to gypsum dust over working lifetimes.

With regard to the World Trade Center (WTC) tragedy, the medical and scientific literature show that soluble gypsum fibers dispersed into the air on that day and possibly for days thereafter would not cause irreversible health effects. The results of *in vitro* and *in vivo* experimental data conclusively show that gypsum fibers are rapidly soluble in biological fluids and in lung tissues. Additionally, one animal study results suggested that gypsum may be protective against respirable crystalline silica. And a recent *in vitro* study investigating the ability of fibers and asbestos-containing cement (ACC) dust to induce radical oxygen species (ROS) or radical nitrogen species (RNS) in hamster lung cells showed no induction of ROS/RNS in the gypsum treated cells. Also, in an experiment whereby gypsum dust was mixed with ACC dust and the mixture was applied to lung cells, gypsum did not enhance (not additive) the toxicity of the asbestos cement dust.

Such cell tests are important for the assessment of a potential toxicity. The toxicity of biopersistent (durable) fibers is thought to include a number of processes at the cellular level. The production of reactive oxygen and reactive nitrogen species (ROS and RNS) are believed to be the most important ones. ROS and RNS can be produced by the prolonged activity of macrophages against durable fibers. ROS/RNS can cause various kinds of damage to DNA. These altered DNA can be detected in the DNA of human or animal cell lines when exposed to durable asbestos fibers. Since calcium sulfate is not a toxic substance and because it is soluble, it is not surprising that it would not induce ROS/RNS in lung cells.

Furthermore, studies have indicated that the property of the very fine dust thought to cause respiratory health problems in the workers and New York City residents was its high pH. Airborne dust samples collected in the immediate aftermath of the collapse had high pH values (pH = 9-11). This high alkalinity is thought to have contributed to the intense respiratory irritability observed in workers and residents exposed to these dusts (Landrigan et al, 2004)

.

Gypsum and gypsum dusts, however, exhibit neutral or nearly neutral pH values (pH = 7.0 – 7.5). A contribution by gypsum dust to these respiratory problems is difficult to imagine. Because of this, and together with the studies that have observed no adverse effects from animal exposure to gypsum dusts, the possibility of soluble airborne gypsum dust adding to the adverse health effects observed in many New York City residents following 9/11 appears remote.

In summary, repeated studies over the years in many contexts have consistently established that gypsum fibers are highly soluble in fluids, including lung fluids, and do not persist in the body. As a result, a wealth of data demonstrates that gypsum causes no health effects (other than transitory irritations from exposure to high levels of fibers) and is not considered carcinogenic.

Review of Safety Assessments of Gypsum Dusts

Identity and Occurrence

Gypsum [CAS 13397-24-5] is a mineral with a chemical composition of $CaSO_4 \cdot 2H_2O$. Phases of gypsum include gypsum rock, gypsite, alabaster (a fine-grained translucent form), selenite which is a transparent crystalline form, and satin spar (a silky form of selenite) (Merck Index, 1976; ILO, 1971). The dehydrated phase of gypsum is the mineral anhydrite [$CaSO_4$; CAS #14798-04-0]. Karstenite, muriacite, anhydrous sulfate of lime, and anhydrous gypsum are synonyms of anhydrite.

Natural gypsum is quarried or mined in many places in the world. In addition synthetic gypsum can be obtained from flue gas desulfurization (FGD) or as a byproduct of a chemical titanium dioxide sulfate process. FGD gypsum [calcium sulfate dihydrate CAS #10101-41-4] has the same chemical composition as natural gypsum, $CaSO_4 \cdot 2H_2O$. The primary use of synthetic gypsum is in the production of wallboard.

Natural and synthetic gypsum are essentially the same material. This is illustrated with the chemical analyses given in Table 1 of both types of gypsum representing sources present in North America and Germany. Most of the data given for North America samples are unpublished results of analyses conducted for USG. The number given for the number of samples represents the number of different sources analyzed and not the number of analyses. For the purposes of this review, natural and synthetic gypsums will be referred to as "gypsum."

Natural gypsum is quarried or mined in many places in the world. In addition synthetic gypsum can be obtained from flue gas desulfurization (FGD) or as a byproduct of a chemical titanium dioxide sulfate process. Synthetic gypsum is used in the production of wallboard.

Natural and synthetic gypsum are essentially one and the same material in terms of chemical make up. Table 1 shows that the trace metal concentrations present in both are very similar. For the purposes of this review, natural and synthetic gypsums will be referred to as "gypsum."

Manufacture

When ground gypsum is heated, it loses its chemically-bound water and becomes calcium sulfate hemihydrate [($CaSO_4 \cdot ½H_2O$, CAS #26499-65-0], also reference as plaster of paris and sometimes shorten to just plaster or just hemihydrate. When water is mixed with this plaster, a paste is formed which sets as gypsum or calcium sulfate dihydrate. This discovery made gypsum one of the world's most useful materials and provided versatile building products in ancient and modern times.

Table 1. Metal Contents of FGD or Quarried Gypsum Samples from N. American or German Sources

	FGD Gypsum (ppm)					Mined or Quarried Gypsum (ppm)				
Metal, *Source*	#	Mean	SD	Min	Max	#	Mean	SD	Min	Max
Antimony, *N. American*	27	0.07	0.05	ND	0.23	17	0.06	0.04	ND	0.12
Arsenic, *N. American*	26	1.39	1.06	ND	3.9	17	0.55	0.39	ND	1.5
Arsenic, *German*	15	1.28	0.83	0.21	2.70	12	1.72	1.21	0.22	3.79
Barium, *N. American*	26	13.1	14.1	0.2	57	17	8.08	7.57	0.39	24.4
Beryllium, *N. American*	28	0.07	0.09	ND	0.18	16	0.03	0.016	ND	0.07
Beryllium, *German*	15	0.20	0.19	ND	0.65	12	0.37	0.25	ND	0.71
Bismuth, *N. American*	26	0.03	0.02	ND	0.08	17	0.021	0.024	ND	0.03
Cadmium, *N. American*	26	0.17	0.19	ND	0.9	16	0.09	0.17	ND	0.52
Cadmium, *German*	15	0.08	0.09	ND	0.29	17	1.25	1.37	ND	4.2
Chromium, *N. American*	27	2.47	1.56	0.26	6.7	17	1.25	1.37	ND	4.2
Chromium, *German*	15	3.36	2.13	1.02	9.72	12	7.49	8.19	0.65	24.9
Cobalt, *N. American*	27	0.55	0.33	0.17	1.38	17	0.76	0.87	ND	2.6
Cobalt, *German*	15	0.47	0.58	0.04	2.20	12	1.37	1.57	0.01	4.39
Copper, *N. American*	27	1.15	0.76	0.23	3.4	17	1.86	2.23	ND	8.2
Copper, *German*	15	3.09	2.17	1.10	8.56	12	5.48	5.14	0.01	14.0
Lead, *N. American*	27	1.03	1.67	0.07	9	17	3.61	5.84	0.28	21.6
Lead, *German*	15	6.52	6.64	ND	22.00	12	4.95	7.08	ND	21.41
Mercury, *N. American*	24	0.237	0.287	0.05	1.12	17	<0.02 (ND)	<0.02 (ND)	<0.02 (ND)	<0.02 (ND)
Mercury, *German*	15	0.60	0.38	0.03	1.32	12	0.04	0.03	ND	0.09
Molybdenum, *N. American*	27	0.55	0.40	ND	1.58	17	0.37	0.47	ND	1.28
Nickel, *N. American*	27	2.30	1.49	ND	5.8	17	1.30	1.79	ND	5.9
Nickel, *German*	15	2.45	3.17	0.3	12.90	12	4.44	5.02	0.3	13.40
Selenium, *N. American*	24	3.54	2.40	ND	11.2	16	0.34	0.40	ND	1.14
Selenium, *German*	15	4.57	5.01	ND	15.70	12	0.08	0.04	ND	0.18
Silver, *N. American*	27	< 0.02 (ND)	< 0.02 (ND)	< 0.02 (ND)	< 0.02 (ND)	17	0.04	0.09	ND	0.38
Thallium, *N. American*	26	0.043	0.031	ND	0.13	17	0.1	0.15	ND	0.51
Thallium, *German*	15	0.24	0.26	ND	0.42	12	0.12	0.06	ND	0.20
Tellurium, German	15	ND	ND	ND	ND	12	ND	ND	ND	ND
Vanadium, *N. American*	27	3.62	6.49	ND	35	17	5.15	10.79	ND	42.7
Vanadium, *German*	15	3.65	1.61	1.22	7.70	12	7.75	8.45	0.93	26.40
Uranium, *N. American*	27	0.50	0.38	ND	1.46	16	0.31	0.44	ND	1.7
Zinc, *N. American*	27	8.52	6.67	0.96	28.8	17	11.90	21.44	ND	78
Zinc, *German*	15	20.18	18.34	ND	53.20	12	16.60	13.20	ND	41.0

FGD = Flue gas desulfurization process); # = Number of Samples; SD = Standard Deviation; Min = minimum value; Max = maximum value; Detection Limits ranged from 0.01 to 2 ppm per sample, but were typically 0.02 ppm; ND = Not Detected

German values from Beckert J, Einbrodt, HJ, Fischer M (1990) Studies to assess the health aspects of natural gypsum and FGD gypsum from coal-fired power plants with regard to the use of these gypsums in the production of building materials. Sponsored by Research Association of Large Power Plant Operators, Essen and the Federal Association of the Gypsum and Gypsum Board Industry, Darmstadt.

Most American values provided by USG and samples analyzed by ICP-MS for most elements. North American values from Kocman V (1998) Modern methods for the analysis of flue gas and by-product gypsums. In: New Frontiers for Byproduct Gypsum. McAdie, HG, Compiler, ORTECH International, Ontario, 1988, 155 as reported in

Table 5, page 377 of JE Rechcigle, ed, Soil Amendments and Environmental Quality. Lewis Publishers, New York, 1995.

Uses

In ancient times gypsum was referred to as "gypsos" ("to burn earth") in Greek, "gatch" in Persian and "gypsum" in Latin. Egyptians, Iranians, Babylonians, Greeks and Romans used gypsum plaster to build exterior and interior structures. Examples include the walls of Jericho, the pyramid of Cheops, the palace of Knossos, and the decorated interior walls of Pompeii.

Today mined, quarried or synthetic gypsum has many uses. Gypsum α ("alpha") - hemihydrate is used in the production of wallboard, tiles, blocks and plasters for the building industry.

Gypsum is used as a heavy clay soil conditioner, in the manufacture of plaster of Paris and Portland cement, as a filler and white pigment for paints, enamels, toothpaste, paper and insecticide dusts. Gypsum has dental applications and is used for bone reconstruction (Wright Medical Technology, Inc., http://www.wmt.com). Plaster of Paris is used in plaster finishes, moldings, plaster casts and statuary.

Food and pharmaceutical - grade gypsums are used as fillers in foods and additives to many pharmaceuticals. These gypsums comply with US FDA pure food and drug laws and enjoy GRAS (**G**enerally **R**egarded **A**s **S**afe) status (FDA GRAS for human (21 CFR 184.1230) and livestock (21 CFR 582.5230) Table 1).

Both calcium and sulfur are essential body constituents and are normal, readily excreted components of the diet. The joint FAO/WHO expert Committee on Food additives did not specify an ADI (Allowable Daily Intake), concluding that there was no information to suggest that its use as a food additive would have any toxic effects at normal dietary exposure (European Chemicals Bureau. IUCLID Dataset, p.118).

Gypsum is also used in water treatment and polishing powders, and in the manufacture of sulfuric acid, calcium carbide, ammonium sulfate and porous pigments. Soluble anhydrite is used as a drying agent. Gypsum has been used for centuries in agriculture as a soil conditioner, a source for calcium and sulfur plant nutrients, for reclamation of sodic soils and abandoned mine spoils and for erosion control and repair of eroded slopes.

Human Health Studies

Acute exposures: human data

Gypsum dust has an irritant action on mucous membranes of the upper respiratory tract (nose, nasal passages, throat and upper airways) and eyes (HSDB, 1998).

Cain et al, 2004 exposed 12 lightly exercising men to controlled dust aerosols of sodium borate (5 to 40 mg/m^3), calcium sulfate (10 to 40 mg/m^3) or calcium oxide (1 to 5 mg/m^3) for 20 minutes to chart chemosensory feel (chemesthesis) of the nose, throat or eyes. The subjects perceived all three dusts, although they perceived calcium sulfate only at the higher concentration (40 mg/m^3). For calcium sulfate no difference was perceived for exposure to 10 mg/m^3 calcium sulfate and exposure to air alone (no calcium sulfate aerosol exposure).

Prolonged or Chronic (Long-Term) Exposure to Calcium Sulfate (Gypsum)

Conjunctivitis has been attributed to prolonged eye exposure (Richardson and Gangolli, 1993).

Prolonged occupational exposure to calcium sulfate dust may cause drying out of mucous membranes, coughing, rhinitis (runny nose), laryngitis, pharyngitis, and impaired sense of taste and smell (HSDB, 1998; Richardson and Gangolli, 1993).

In the early 20th century health workers and medical researchers observed no or minimal adverse health effects among workers and miners exposed for years to airborne gypsum dust. Hunter states that calcium sulfate caused no lung disease in calcium sulfate miners (Hunter, 1975).

In studies to evaluate the respiratory effects of dust exposure to gypsum miners, no symptoms or pulmonary abnormalities were seen (Sayers and Riddel, 1934; Brumfield, 1939). Pneumoconiotic changes of small rounded opacities were observed in the lungs of some miners, but were correlated with the level of silica in the environment.

Riddel reported no permanent health effects in workers exposed for many years to gypsum dust (Riddel, 1934). This observation was later confirmed by an autopsy study of workers who had substantial exposure to gypsum dust during their employment. (Brumfield, 1939).

An investigation of the possible effects of gypsum dust on the respiratory tract of miners was carried out by Oakes et al, 1982. Participants (241 male workers employed in four mines) undertook lung function tests and were examined by chest X-rays. Airborne dust samples were taken for various job categories and analyzed for respirable dust and respirable silica content. Two of the mines had higher respirable silica content (estimated to average 0.12 mg/m^3 for top exposure levels) than did those of the other two mines (estimated average of 0.07 mg/m^3 for top exposure levels). In mines where the respirable silica content of the dust was higher, the lungs of 13 of 43 men aged 35 years or more with at least 20 years of service showed small opacity profusions (mild pneumoconiotic changes) while the radiographs of 3 of 23 men aged 35 years or more with 20 or more years of service in the mines showed small opacities in lung tissue. The authors concluded that dust hazard in the mines was most likely associated with respirable quartz exposure and not with gypsum dust exposure. Parkes, 1982 notes that in cases followed by the author for some 20 years, the lesions had shown little tendency to progress.

<u>Medical Applications: Clinical and Animal Studies</u>

Calcium sulfate has been safely used in orthopedics for more than 100 years (Heyybeli et al, 2003). Calcium sulfate hemihydrate (plaster of Paris) has been used clinically as an osseous filler and shown not to increase the normal inflammatory response to trauma, to elicit foreign body reaction and to allow for the ingrowth of normal bone (Rosenblum et al, 1993).

The radiographic and histologic appearances of refined calcium sulfate have been studied in many experimental animal models and in clinical applications. In these studies refined gypsum has been used as a synthetic bone graft, a graft expander (synergistic combination of calcium sulfate with demineralized bone matrix) and a method for local delivery of antibiotics (Rosenblum et al, 1993; Heybelli et al, 2003). These studies have shown excellent biocompatibility and complete resorption of calcium sulfate. They also showed that calcium sulfate is effective as an osteoconductive medicated bone-graft substitute, achieving a predictable local response and long-term release of the drug over weeks without adverse systemic effects and with undetectable systemic levels within 24 hours (Turner et al, 2001).

Animal Studies

Animal Studies: Acute Exposure

Calcium sulfate applied to eyes of rabbits as a watery paste was found to be harmless (Grant, 1974; HSDB, 1998).

The acute oral toxicity of calcium sulfate is low for rats and mice: LD50 rat > 5000 mg/kg body weight (BW) and 4052 – 4226 mg/kg BW for mice. (Ulmans Encyclopedia of Industrial Chemistry; Kawahara, 1992).

Animal Studies: Teratologic Effects

The administration of up to 1600 mg /kg (body weight) of FDA 71-86 (calcium sulfate) to pregnant mice or rats for 10 consecutive days or to pregnant rabbits for 13 consecutive days had no clearly discernible effect on nidition (natural process whereby a fertilized egg becomes implanted in the lining of the uterus of placental mammals) or on maternal or fetal survival. The number of abnormalities seen in either soft or skeletal tissues of the test groups did not differ from the number occurring spontaneously in the sham-treated controls. (Food and Drug Research Labs, Inc., 1974).

Animal Studies: Subchronic Exposure: Intratracheal

Breining et al., 1990 used the intratracheal test to study anhydrite, cadmium sulfide, titanium dioxide, polyvinyl-N-oxide (PVNO) and Döorentruper quartz (DQ) separately or in mixtures with quartz (DQ). Female Wister rats (each about 200 grams in weight) were instilled with varying amounts of dusts or dust mixtures suspended in 0.5 ml saline solution. The rats were sacrificed three months later and lungs were removed. Half of each left lung was hydrolyzed, cooled, filtered and neutralized with sodium chloride, and the total hydroxyproline content was measured. The remaining left lung half was weighed, homogenized and extracted with chloroform-methanol, and the total lipid content was determined.

For rats treated with anhydrite (35 milligrams instilled) no increase in total lipid or hydroxyproline lung content was observed when compared to control animals. Separate quartz instillations (2, 5, 7, or 11 mg) in rats resulted in dose-dependent increases in total lipid and total hydroxyproline lung content indicating tissue injury.

Successive and simultaneous instillations of anhydrite and quartz led to marked reductions in total lipid and hydroxyproline lung contents compared to quartz instillations alone, suggesting a protective effect for gypsum anhydrite.

Histological examination showed inflammatory changes in lung and lymph node tissue samples from quartz – treated animals. Quartz treatment caused many disseminated histiocytic nodules with distinct formations of collagenous connective tissue (fibrosis). The content of these pathological changes was dose – dependent. Additionally, alveolar proteinosis (damage to air sacs where gas exchanges occur in lung tissue) was observed.

Successive instillations of 35 milligrams of anhydrite and 11 mg of quartz resulted in distinct nodular histiocytic reaction without fibrosis, suggesting a protective effect of anhydrite. Additionally, simultaneous instillation of 2 mg quartz with 35 mg anhydrite caused a minimal reaction in lymph nodes with a suggestion of nodule formation without fibrosis. In all anhydrite-quartz groups and independent of the anhydrite dose, numerous birefringent crystals were observed, without increase in connective tissue component or alveolar proteinosis (Breining et al, 1990).

<u>Animal Studies: Subchronic: Inhalation</u>

Clouter et al, 1997 exposed nose-only 2 groups of male Fischer 344 rats (36 per group) to a 100 mg/m^3 aerosol of anhydrous calcium sulfate (Franklin® Fibers also known as gypsum A-30 – see *in vitro* solubility study described below) for 6 hours/day, 5 days/week for 3 weeks to study its effect on macrophages, glutathione concentration and γ – glutamyl transpeptidase (γ - GT) activity in extracellular bronchoalveoloar lavage fluid (BALF). BALF is a marker of cell toxicity, and γ - GT activity provides a very sensitive index of cellular damage.

One animal group was sacrificed after the 3-week exposure period and the other group was followed for 3 more weeks. A control group of animals were exposed to air only. No effects were observed on the number of macrophages per alveolus, extracellular bronchoalveoloar lavage fluid (BALF) protein concentrations, or BALF γ - GT activity. After 3 weeks of non-exposure, the calcium sulfate – exposed animals showed increased non-protein sulfydryl levels (NPSH; mainly glutathione). No difference was observed between the cell viability of type II pneumocytes of the calcium sulfate – exposed animals and control animals.

In a follow-up study, Clouter et al, 1998 exposed 3 groups of male Fischer 344 rats to a targeted 10 mg/m^3 aerosol of crocidolite or calcium sulfate fibers (actual calcium sulfate aerosol concentrations averaged 15 mg/m^3) or air for 6 hours /day, 5 days/week for 3 or 4 weeks. Animals were sacrificed immediately or 4 weeks after exposure. Lungs were removed, ashed and postcaval lobes were examined for crocidolite fibers or gypsum fibers using scanning electron microscopy and calcium levels using inductively coupled plasma spectroscopy.

No gypsum fibers were found in any of the analyzed samples despite measuring airborne fiber levels averaging 15 mg/m^3. Calcium levels in ashed lung did not differ between exposed and control rats. Even calcium sulfate fiber-exposed animals which were immediately killed following exposure did not exhibit raised calcium levels. However, histological sections of showed the presence of calcium sulfate fibers in lung tissue, proving that respirable gypsum fibers had indeed reached the alveoli region.

In sharp contrast, crocidolite fibers numbered 12 to 13 million fibers per milligram of ashed lung samples from animals sacrificed immediately after exposure and 5.46 million crocidolite fibers per milligram of ashed lung samples from animals sacrificed 4 weeks after exposure. Animals sacrificed 4 weeks after crocidolite exposure showed significantly elevated (γ - GT) activity in BALF. In contrast, (γ - GT) activity was significantly reduced 4 weeks following exposure to calcium sulfate fibers.

Animal Studies: Long-Term Inhalation

Schepers et. al, 1955 published results of a study in which guinea pigs were exposed to airborne calcined gypsum dust (16,000 particles per cubic centimeter) for two years with no observed adverse reactions. Surviving animals lived another two years. Thereafter they were sacrificed and their lungs were examined. The authors concluded: "the effect of calcined gypsum dust on the lungs of guinea pigs for two years was too insignificant to be classified as pneumoconiosis....It has been demonstrated that the small increments of fine calcined gypsum particles inhaled into the lung largely disappear, apparently as a result of solution in the tissues." (Schepers et al, 1955)

Animal Studies: Long-Term Studies Intra-Cavitary Studies

Intratracheal Studies

Intratracheal studies are used to test the potential of a fiber or particle to induce tumors or other chronic diseases in experimental animals. There have been at least three such studies involving gypsum.

In 1974 Wright and Kushner directed a study to identify, evaluate and characterize the effects of a single intratracheal instillation of calcium sulfate anhydrite whisker

(Franklin®Fibers) in male albino rats (Hazelton Laboratories, Inc., 1976; Wright, 1986). The research was carried out on animals maintained in animal care facilities fully accredited by the American Association for Accreditation of Laboratory Animal Care.

One hundred and fifty animals were divided into six groups: vehicle control (physiologic saline solution); 10 milligram (mg) dose graphite group (negative control); 10 mg quartz group (positive control); 0.1 mg $CaSO_4$ dose group (low dose); 1.0 mg $CaSO_4$ dose group (middle dose); and 10 mg $CaSO_4$ dose group (high dose).

Five animals were randomly chosen from each group and sacrificed at 24 hours, one week, 4 week, and 13 week intervals. All surviving animals (one vehicle control animal succumbed) of all groups were sacrificed six months after exposure. Tissues (lung, trachealbronchial lymph node, spleen, kidney, liver and any unusual lesions or tissue masses) were preserved in 10% neutral buffered formalin. Lung weight for each sacrificed rat was measured, and all preserved tissues from all groups were examined microscopically. Statistical evaluations were carried out for growth and survival analysis, terminal body weights, lung weights and lung/body weight ratios.

The authors reported that no biologically significant signs of compound-induced system toxicity were observed among animals in the calcium sulfate whisker fiber dose groups throughout the 6 month study period. They noted that histomorphological alterations attributed to calcium sulfate anhydrite fibers were not apparent at any dosage levels at any of the sacrifice intervals. Positive (silica-exposed) control rats developed silicotic nodules consisting of macrophages, fibroblasts, occasional collage strands, and quartz crystals (fist evident at the one month sacrifice). These lesions were observed in lung, thymus and peribronchial lymph node sections and persisted to the end of the study period.

Bartmann, 1988 intratracheally administered 25 mg REA gypsum (an FGD gypsum) under nonsterile conditions to 48 young (weight 220 grams), healthy female Wistar type F 90 rats. Thirty-seven untreated animals served as controls. Scheduled sacrifices were carried out on selected animals after 24 hours, and 1, 3, 8 and 18 months. Histological preparations of the right upper lobe of the lung and mediastinal lymph nodes were prepared for each animal. The preparations were stained and histologic examinations were carried out under a light microscope.

Gypsum was not detectable using light microscopy in lung tissue samples from animals which had been exposed for 24 hrs and then immediately sacrificed. At 18 months, no differences could be found between the lung tissue samples from the gypsum treated animals and those from the control animals. No pulmonary fibrosis was observed in the calcium sulfate treatment rats.

Although this study apparently did not follow GLP (Good Laboratory Practices), its results do not differ from the results of the prior intratracheal study described above.

Adachi et al (1991) intratracheally administered (2.0 mg/animal each week for 5 weeks for a total of 10 mg/animal) calcium sulfate whiskers to 20 Syrian hamsters and histologically observed the animals for two years after administration. They observed 3 tumors during this time period: a kidney tumor, a rib tumor and a heart tumor. Given the fact that hamsters are known to exhibit spontaneous tumors unrelated to the test material administered, the documented and well known solubility of gypsum fibers in biological fluids, and the unconventional and not recommended multiple instillations of the test material which causes repeated trauma and injury at the sight of injection, the results of this study are questionable. This study has never been repeated, and interpretation of these results is difficult if not impossible.

Intraperitoneal Studies

For the purposes of estimating the potential of fibers to induce tumors in experimental animals, intrapleural and intraperitoneal studies in rats have been shown to be the most sensitivity of available test methods. Pott and Friedrichs, 1972 injected gypsum fibers into the peritoneal cavities of rats in a long term (over two years) tumorgenicity study. They found that gypsum fibers were easily soluble in the peritoneal cavity and concluded that the chemical composition of fibers was not responsible for the observed carcinogenesis of other long/thin fibers. Rather, the degree of carcinogenic potency of a fiber depended on the extent to which it retained its fibrous structure (Pott and Friedrichs, 1972 as cited by Pott et al, 1984 and Pott et al, 1994).

Gypsum fibers exhibit a very low durability (low biopersistence) in the body and, therefore, have little or no chance to exert deleterious effects on surrounding tissue because they lose their fibrous structure very rapidly and dissolve into cellular fluids very quickly. Pott, 1987 hypothesized a "durability threshold" – "The persistence of fibres in the tissue is a very important property with regard to their carcinogenic effect because the formulation of a tumor takes many years or some decades. It can be assumed a fibre has to remain by the bronchial or serosa tissue until the induction of tumor cells occurs." (Pott, 1987).

Long/thin gypsum fibers dissolve in lung or body fluids within minutes or hours, and do not exhibit tumorgenicity potential.

Other Relevant Data

Tests for Mutagenicity

Gypsum was not mutagenic in the Ames test with or without activation (Bartmann, 1986; Cremer et al, 1988; Simonen, 1991). The Ames mutagenicity test is simple to conduct and easy to standardize. It is based on mutants of the bacteria *Salmonella typhimurium* which are very suitable for recording gene mutations when a foreign substance such as gypsum is applied to them. In the activated Ames test the mutants are incubated with S-9 fraction of a rat liver homogenate recovered from animals that were previously treated with polychlorinated biphenols (PCBs) which are strong inducers of liver enzymes. The S-9 fraction is necessary for metabolic activation because some mutagenic or carcinogenic substances are not especially toxic and would not be expected to activate liver enzymes. Activated liver enzymes may change (metabolize) test substances into forms or by products which are themselves mutagenic or carcinogenic.

Tests for Cell Toxicity

Mammalian macrophage and non-macrophage cell lines have been used to study the effects of non-asbestiform dusts. Gypsum was inert with respect to three cell lines (Chamberlain et al, 1982).

The toxicity of biopersistent fibers is thought to include a number of processes at the cellular level. The production of reactive oxygen and reactive nitrogen species (ROS and RNS) are believed to be the most important ones. ROS and RNS can be produced by the prolonged activity of macrophages against durable fibers. ROS/RNS can cause various kinds of damage to DNA. These altered DNA can be detected in the DNA of human or animal cell lines when exposed to durable asbestos fibers.

Dopp et al., 2005 used V79-cells (Chinese hamster lung cells to show the cytotoxic (cell toxicity) and genotoxic potential of asbestos-cement powder compared to that of chrysotile ("positive" control) and untreated V79-cells. Gypsum was selected as the "negative" control (cells that were treated with a substance that is known not to have an effect on the cells – a quality control check). At all dose levels (1, 5, 10 and 20 micrograms per square centimeter) and length of exposure (24, 48 and 72 hours) gypsum did not induce micronuclei (DNA damage) formation. Gypsum was negligibly cytotoxic (equal to the negligible cytotoxicity observed for untreated V79-cells) up to the highest exposure level and did not have any effect on cell viability at longer exposure times (48 and 72 hours). Additionally, gypsum did not enhance toxicity (additive effect) when mixed with asbestos-containing cement dust and the mixture was applied to cells (Dopp et. al, 2005).

Solubility Study in a Simulated Lung Fluid Environment

In 1987 USG Research completed work designed to investigate the retentions of FRANKLIN FIBERS® and gypsum fibers in a simulated lung fluid environment. The solubilities of FRANKLIN FIBERS®, H-30, and acicular gypsum (AG) were measured in flowing (~ 2.5 ml/hr) Ringer's Injection solution or in flowing (~2.5 ml/hr) deionized water at 37 degrees F. The *in vitro* technique was similar to other methods (Förster, 1984 and Scholze and Conrad, 1987) developed as screening tools for the prediction of *in vivo* fiber durability.

Atomic absorption measurements were used to calculate percent dissolution of calcium compounds after 6, 12, 24, 48, 120 and 168 hours and were confirmed by gravimetric and visual checks. Calcium sulfate fibers dissolved readily in Ringer's solution (half-time of 29 hours) and water (half-time of 58 hours). After 168 hours almost all calcium sulfate fibers were dissolved in the Ringer's solution compared to 80% dissolved or calcium sulfate fibers in the flowing water stream. (United States Gypsum Company Research Center, 1987)

Relevant Health Regulations

Carcinogenicity

The universally recognized solubility and lack of tumorigenic potential of gypsum fibers is recognized by European and German regulatory bodies. For example, the German regulations TRGS 906-1 and TRGS 905 regulation ("Technical Rules for Hazardous Materials," Issue June 1997/Version November, 1997 and Appendix 1, "Third Regulation in order to modify the Regulation on Hazardous Substances," July 25, 1994) contain language by which a fiber is exonerated as a carcinogen. Paragraph 4 [page 7 of the translation] of the TRGS 905 document specifically notes that gypsum is not to be considered carcinogenic:

"(4) Under special circumstances, a classification different from Paragraphs 2 and 3 [Category 2 or 3 classification] can take place if suitable data are presented by the manufacturer of the fibers – for example:

- Data which prove a very low biostability (**for example, comparable with gypsum fibers)** (emphasis is added);"

Paragraph 6 [page 8 of the translation attached] of the TRGS 905 document states:

"(6) All other inorganic types of WHO fibers are classified as Category 3, if the animal experiment results under consideration (including data for biostability) are not sufficient for a classification as Category 2. This concerns the following at present:

- Halloysite
- Magnesium oxide sulfate
- Nemalite
- Sepiolite
- Inorganic fibrous dusts, if not mentioned (**with the exception of gypsum fibers** and wollastonite fibers)." (Emphasis is added)

The German TRGS 905 stipulates that WHO fibers* must have a half-life in rat lungs of 40 days or less in order not to fall under the TRGS 905 classification (see Appendix 1, p. 5 : "Attachment V No. 7 Synthetic mineral fibers") . Since gypsum fibers had a half-life in rat lungs that was less than 24 hours in the subchronic inhalation study of Clouter et al (1998) and in the Kushner and Wright, 1976 and Bartmann, 1988 intratracheal studies, they do not fall under this regulation and are not considered tumorigenic.

* a WHO fiber is any particle that has a length greater than 5 micrometers, a fiber diameter less than 3 micrometers and a length: diameter ration larger than 3:1. Such fiber dimensions are thought to possess the highest potential for carcinogenicity.

Other Health-Based Regulations

Table 2 lists workplace regulations for gypsum dusts. Gypsum is considered a nuisance dust, not otherwise specified (NOS).

Table 2. Occupational Exposure Limits* for Calcium Sulfate in Various Countries

Country	Exposure Limit (mg/m^3)	Reference
Netherlands – Ministry of Social Affairs and Employment	10 (total inhalable dust)	SZW
Germany		
AGS	6 (respirable dust)	TRG
DFG MAK – Commission	6 (respirable dust)	DFG
Great Britain – HSE	10 (total Inhalable Dust) 4 (respirable dust)	HSE
USA		
ACGIH (TLV)	10 (Particulate matter containing no asbestos and <1% crystalline silica)	ACGIHa
OSHA (PEL)	15 (total inhalable dust) 5 (respirable dust)	ACGIHb
NIOSH (REL, 10-hr TWA)	5 (respirable dust)	ACGIHb
*8-hour Time Weighted Average unless otherwise specified		

ACGIHa American Conference of Governmental Industrial Hygienists (ACGIH). 2002 TLVs and BEIs. Threshold Limit Values for chemical substances and physical agents. Biological Exposure Indices. Cincinnati OH: ACGIH, Inc, 2002.

ACGIHb American Conference of Governmental Industrial Hygienists (ACGIH). Guide to occupational exposure values – 2002. Cincinnati, OH: ACGIH, Inc. 2002.

HSE Health and Safety Executive (HSE). EH40/2002. Occupational exposure limits 2002. Sudbury (Suffolk), England: HSE Books, 2002: 19, 24.

SZW Ministerie van Sociale Zaken en Werkgelegenheid (SZW). Nationale MAC-lijst 2002. The Hague, the Netherlands: Sdu, Uitgeverij, 1990: 34, 43 (Report # RA9/90).

TRGS 900 Grenzwerte in der Luft am Arbeitsplatz; Technische Regeln fur Gefahrstoffe. BarbBl 2000; 2.

References

American Conference of Governmental Industrial Hygienists (ACGIH) Documentation of the Threshold Limit Values and Biological Exposure Indices. 6th ed. Cincinnati OH, 1991:204-205.

Bartmann C (June 26, 1986) Biological Effects of a Flue Gas Desulfurization Gypsum Produced by the Limestone Process. Dissertation approved by the Medical Faculty of Rhine-Westphalian Technical University Aachen for Granting of the Academic Degree of Doctor of Medicine. pp. 1-68. NTIS Publication. U.S. Department of Commerce. DE88770258. Translated from the German by the McElroy Translation Company, 910 West Ave., Austin, TX 78701, May 3, 2006.

Beckert J, Einbrodt, HJ, Fischer M (1990) Studies to assess the health aspects of natural gypsum and FGD gypsum from coal-fired power plants with regard to the use of these gypsums in the production of building materials. Sponsored by Research Association of Large Power Plant Operators, Essen and the Federal Association of the Gypsum and Gypsum Board Industry, Darmstadt.

BIBRA (British Industrial Biological Research Association) Toxicity Profile: Calcium Sulphate, cited by European Chemicals Bureau. IUCLID Dataset. European Commission. 2000.

Breining H, Rosmanith J, Ehm W (1990) et al. The different biological effects of dusts applied intratracheally, separately or in mixtures in rats. *Proceedings of the VIIth International Pneumoconiosis Conference: Part 1*. Pittsburgh, PA August 23 – 26, 1988. Centers for Disease Control. U.S. Department of Health and Human Services, DHHS Publication No. 90-108 Part 1, pp. 547-553.

Brumfield DM. Gypsum Industry: Clinical Picture and X-ray findings. *Proceedings of Fourth Saranac Lake Laboratory. Symposium on Silicosis*, 1939; p. 170.

Cain WS, Jalowayski AA, Kleinman M, Lee N-S, Lee B-R, Ahn B-H, Magruder K, Schmidt R, Hillen BK, Warren CB, Culver BD (2004) Sensory and associated reactions to mineral dusts: Sodium borate, calcium oxide, and calcium sulfate. *Jr. Occup. Environ. Hyg.* 1:222-236.

Clouter A and Richards J (1996) Extracellular biotransformation potential in mouse airways. *Int. J. Biochem. Cell Biol.* 29:521-527.

Clouter A, Houghton CE, Bowskill CA, Hibbs LR, Brown RC, Hoskins JA (1997) The effect of inhaled fibers on the glutathione concentration and [gamma] transpeptidase activity in lung type II epithelial cells, macrophages aand bronchoalveolar lavage fluid. *Inhalation Toxicology*. 9:351-367.

Clouter A, Houghton CE, Hibbs LR, Hoskins JA (1998) Effect of inhalation of low doses of crocidolite and fibrous gypsum on the glutathione concentration and [gamma] – glutamyl transpeptidase activity in macrophages and bronchoalveolar lavage fluid. *Inhalation Toxicology*. 10:3 – 14, 1998.

Cremer UH, Pieler et al (1989) Mutagenicity experiments using the Ames test with natural gypsum and (flue-gas) desulphurization gypsum. *Wissenschaft und Umwelt ISU,* 4, 202-205. as cited in European Chemicals Bureau. IUCLID Dataset. European Commission, 2000.

Dopp E, Yadav S, Ansari FA, Bhattacharya K, Recklinghausen U, Rauen U, Rödelsperger K, Shokouhi B, Geh S, Rahman Q. ROS-mediated genotoxicity of asbestos-cement in mammalian lung cells *in vitro. Particle and Fibre Toxicology* 2005 2:9. available at http://creativecommons.org/licenses/by/2.0

FDA GRAS for human (21 CFR 184.1230) and livestock (21 CFR 582.5230) Table 1.

Food and Drug Research Labs, Inc., Teratologic Evaluation of FDA 71-86 (Calcium Sulfate) in Mice, Rats and Rabbits. 1974: 1-42. PB234873 National Technical Information Service. U.S. Department of Commerce.

Grant WM. Toxicology of the Eye. 2nd ed. Springfield, IL: Charles C. Thomas, 1974, 225.

Hazleton Laboratories, Inc., (July 26, 1974). Hazleton Laboratories, Inc. 26-Week Intratracheal Toxicity Study in Rats Calcium Sulphate Anhydrite Whisker Fibers, Final Report. Submitted to Franklin Key Inc., Valley Forge, PA, July 26, 1974. pp. 1 – 25.

Heybeli N, Oktar FN, Ozyazgan S, Akkam G, Ozsoy S (2003) Low-cost antibiotic loaded systems for developing countries. *Technology and Health Care.* 11:207-216.

HSDB) US National Library of Medicine (NLM), ed. Hazardous Substances Data Bank (HSDB), 1998.

Hunter D. The Diseases of Occupations. 5th ed., p. 961. The English Universities Press, Ltd., London, 1975; ACGIH Documentation of the threshold limit values and biological exposure indices. 6th ed. Cincinnati OH, 1991:204-205.

International Labour Office. Encyclopedia of Occupational Health and Safety. Vol. I and II. New York: McGraw-Hill Book Co., 1971.630.

Kawahara S (1992) Investigation of oral toxicity effects of quick-lime on mice and rats. *Gypsum Lime*, 241:445-6, 1992, as cited by European Chemicals Bureau. IUCLID Dataset. European Commission. 2000.

Kocman V (1998) Modern methods for the analysis of flue gas and by-product gypsums. In New Frontiers for Byproduct Gypsum. McAdie, HG, Compiler, ORTECH International, Ontario, 1988, 155 as reported in Table 5, page 377 of JE Rechcigle, ed, Soil Amendments and Environmental Quality. Lewis Publishers, New York, 1995.

Landrigan PJ, Lioy PJ, Thurston G, Berkowitz G, Chen LC, Chillrud SN, Gavett SH, Georgopoulos PG, Geyh AS, Levin S, Perera F, Rappaport SM, Small C, and the NIEHS World Trade Center Working Group (May, 2004) Health and environmental consequences of the World Trade Center disaster. *Environmental Health Perspectives.* 112 (6): 731-739; p. 738.

MAK- und BAT-Werte-Liste (1993) Maximale Arbeitsplatzkonzentrationen und biologische Arbeitsstofftoleranzwerte, DFG (Deutsche Forschungsgemeinschaft), Weinheim: VCH, ISSN 0417-1810, ISBN 3-527-27561-4. as cited by European Chemicals Bureau. IUCLID Dataset. European Commission, 2000.

Merck Index. 9th ed. Rahway, NJ: Merck & Co., Inc., 1976:216.

NOSB TAP Materials atabase Complied by OMRI, February 8, 2001, pp 1 – 15.

Oakes D, Douglas, R, Knight K, et al. Respiratory effects of prolonged exposure to gypsum dust. *Ann Ocup Hyg* 1982. 26, 1982:833-840.

Parkes WR. Occupational Lung Diseases. 3rd Edition Butterworth Heinemann, 1982.

Pott. F and Friedrichs KH . Tumoren der Ratte nach ip Injekton faserformiger Staube. *Naturwissenschaften* 59:318, 1972 as cited by Pott F, Roller M, Kamino K, Bellmann B Significance of durability of mineral fibers for their toxicity and carcinogenic potency in the abdominal cavity of rats in comparison with the low sensitivity of inhalation studies. *Environ. Health Perspectives Supplements 6*. Vol 102, Number S5, October, 1994: 145-150.

Pott F, Schlipköter HW, Ziem U, Spurny K, Huth F. New results from implantation experiments with mineral fibres. In: *Biological Effects of Man-Made Mineral Fibres. Vol. 2. Proceedings of a WHO/IARC Conference*, Copenhagen, 20-22 April, 1982. pp. 286 – 302.

Pott F, Roller M, Kamino K, Bellmann B (1994) Significance of durability of mineral fibers for their toxicity and carcinogenic potency in the abdominal cavity of rats in comparison with the low sensitivity of inhalation studies. In: Biopersistence of Respirable Synthetic Fibers and Minerals. *Environmental Health Perspectives. Supplements.* V. 102, Supplement 5, October, 1994, pp. 145 – 150.

Pott F [English Abstract] Fiber as a carcinogenic agent [German]. *Zentralbl Bakteriol Mikrobiol Hyg(B).* V. 184(1) April, 1987: 1-23.

JE Rechcigle, ed, Soil Amendments and Environmental Quality. Lewis Publishers, New York, 1995.

Richardson ML and S Gangolli (eds) C42 Calcium Sulfate. In: The Dictionary of Substances and Their Effects. Cambridge, UK: Royal Society of Chemistry, Vol. 2 1993: 66-67.

Riddell AR. Clinical investigations into the effects of gypsum dust. *Canadian Public Health Journal.* 25, 1934, p. 147.

Rosenblum SF, Frankel S, Ricci JR, Alexander H (1993) Diffusion of fibroblast growth factor from a plaster of Paris carrier. *Journal of Applied Biomaterials.* 4:67 – 72.
Schepers GWH, Durkan, TM Delehant AB (1955) *AMA Arch Ind Health.* 12:329-347.

Simonen T (1991) Leachability and Toxicology of Flue Gas Desulfurization Products and Coal Fly Ash. Imatran Power Company. National Technical Information Service DE2506513. pp. 1 – 80. Translated from the Finnish by McElroy Translation Company, May 3, 2006.

Statement of New York Gypsum Producers Regarding Dust Hazard Classifications Numbered 1164, 1165, 1624, 1703, 4036, 4037. October 31, 1935.

TRGS 906-1 "Technical Rules for Hazardous Materials," Issue June 1997/Version November, 1997

TRGS 905 Appendix 1, "Third Regulation in order to modify the Regulation on Hazardous Substances," July 25, 1994)

Turner TM, Urban RM, Gitelis S, Kuo KN, Andersson BJ (2001) Radiographic and histologic assessment of calcium sulfate in experimental animal models and clinical use as a resorbable bone-graft substitute, a bone-graft expander, and a method for local antibiotic delivery. The Jounal of Bone and Joint Surgery, Inc., Downloaded from www.ejbjs.org on April 28, 2006.

Ullmans Encyclopedia of Industrial Chemistry. Calcium Sulphate, VCH Veinheim, 1985. as cited by European Chemicals Bureau. IUCLID Dataset. European Commission. 2000.

United States Gypsum Company Research Center, Solubility of calcium sulfate fibers in Ringer's solution and in water. Report No. 33062. 12/03/87. pp.1 - 29.

Wright GW (1986) The Biology of Franklin Fiber® Filler. Industrial Gypsum Division, United States Gypsum Company, Chicago, IL. pp. 1 – 4.

ATTACHMENT B

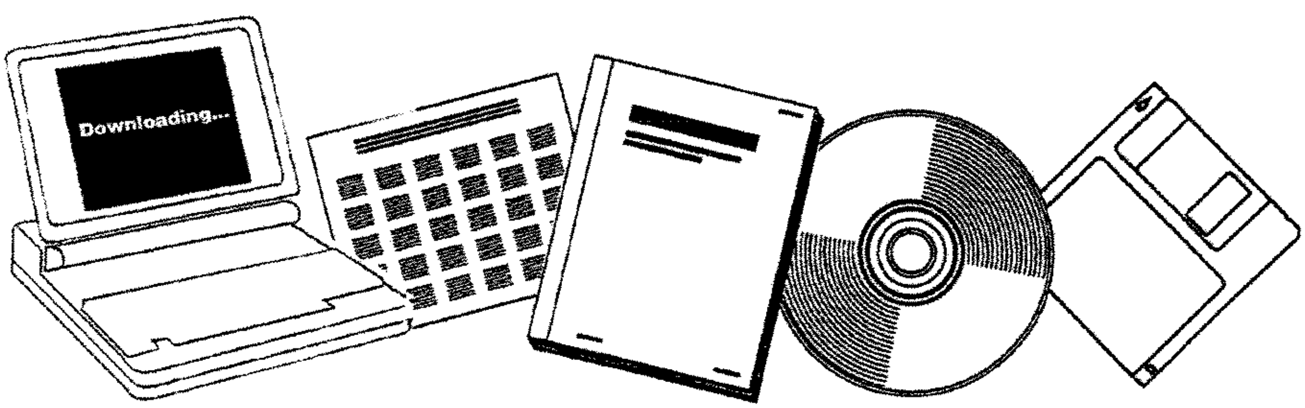
TERATOGIC STUDY

PB234873

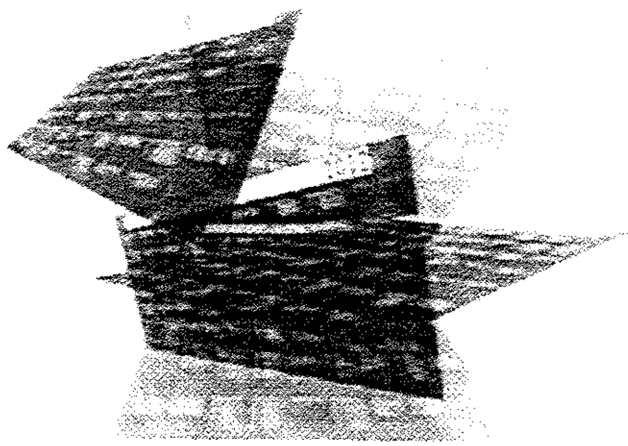
TERATOLOGIC EVALUATION OF FDA 71-86 (CALCIUM SULFATE) IN MICE, RATS AND RABBITS

FOOD AND DRUG RESEARCH LABS., INC.,
WAVERLY, N.Y

FEB 1974



Tailored to Your Needs!



Selected Research In Microfiche

SRIM® is a tailored information service that delivers complete microfiche copies of government publications based on your needs, automatically, within a few weeks of announcement by NTIS.

SRIM® Saves You Time, Money, and Space!

Automatically, every two weeks, your SRIM® profile is run against all *new* publications received by NTIS and the publications microfiched for your order. Instead of paying approximately $15-30 for each publication, you pay only $2.50 for the microfiche version. Corporate and special libraries love the space-saving convenience of microfiche.

NTIS offers two options for SRIM® selection criteria:

Standard SRIM®–Choose from among 350 pre-chosen subject topics.

Custom SRIM®–For a one-time additional fee, an NTIS analyst can help you develop a keyword strategy to design your Custom SRIM® requirements. Custom SRIM® allows your SRIM® selection to be based upon *specific subject keywords*, not just broad subject topics. Call an NTIS subject specialist at (703) 605-6655 to help you create a profile that will retrieve only those technical reports of interest to you.

SRIM® requires an NTIS Deposit Account. The NTIS employee you speak to will help you set up this account if you don't already have one.

For additional information, call the NTIS Subscriptions Department at 1-800-363-2068 or (703) 605-6060. Or visit the NTIS Web site at *http://www.ntis.gov* and select SRIM® from the pull-down menu.

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 605-6000
http://www.ntis.gov

PB234-873

FOOD AND DRUG Research LABORATORIES, INC.

WAVERLY DIVISION
Route 17
P.O. Box 107
Waverly, New York 14892
(607) 565-2931

F I N A L
R E P O R T

Submitted to: DHEW/Public Health Service
Food and Drug Administration CA-272
5600 Fishers Lane-Room 5C-13
Rockville, Maryland 20852

Date November 5, 1973

Laboratory No. 1765 m
Contract No. FDA 71-260

Sample: Fine white powdered material

Marking: FDA 71-86 (Calcium sulfate)

Examination Requested: Teratologic evaluation of FDA 71-86 in mice.

Procedure: See Appendix I

Results: See Tables 1 through 4 and Appendix II

Conclusion:

On the basis of the data presented herein, the following conclusion appears to be warranted:

"The administration of up to 1600 mg/kg (body weight) of the test material to pregnant mice for 10 consecutive days had no clearly discernible effect on nidation or on maternal or fetal survival. The number of abnormalities seen in either soft or skeletal tissues of the test groups did not differ from the number occurring spontaneously in the sham-treated controls."

FOOD and DRUG RESEARCH LABORATORIES, INC.

Kenneth Morgareidge

Kenneth Morgareidge, Ph.D
Vice President

BIBLIOGRAPHIC DATA SHEET	1. Report No. FDABF-GRAS-245	2.	3. Recipient's Accession No.
4. Title and Subtitle Teratologic Evaluation of Calcium Sulfate			5. Report Date February 1974
			6.
7. Author(s)			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Food and Drug Research Laboratories, Inc. Route 17 (P. O. Box 107) Waverly, N.Y. 14892			10. Project/Task/Work Unit No.
			11. Contract/Grant No. FDA 71-260
12. Sponsoring Organization Name and Address U. S. Food and Drug Administration 200 "C" Street, S.W. Washington, D.C. 20204			13. Type of Report & Period Covered Final
			14.
15. Supplementary Notes			
16. Abstracts Teratological test results in three(3) species of animals (mice, rats, and rabbits).			
17. Key Words and Document Analysis. 17a. Descriptors			
17b. Identifiers/Open-Ended Terms			
17c. COSATI Field/Group			
18. Availability Statement Release unlimited		19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
		20. Security Class (This Page) UNCLASSIFIED	22. Price

1<

FORM NTIS-35 (REV. 3-72)

USCOMM-DC

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups: 341 through 346

Material : FDA 71-86

Date: October 5, 1973

Laboratory No. : 1765 m

Table 1

Fate Summary
(Mice)

Group	Material	Dose ** mg/kg	Total: Mated	Total: Pregnant	Surviving at Term: Total	Surviving at Term: Pregnant[1]
341	Sham	0.0	25	22	25	22
342	Aspirin*	150.0	25	19	25	19
343	FDA 71-86	16.0	28	22	28	22
344	FDA 71-86	74.3	24	22	24	22
345	FDA 71-86	345.0	25	24	25	24
346	FDA 71-86	1600.0	30	23	29	22

* Positive Control : 150.0 mg/kg
** Administered as a water solution (10 ml per kg of body weight)
1) Includes all dams examined at term

3<

FOOD AND DRUG RESEA[illegible] LABORATORIES, INC.

Group: 341 through 346

Material: FDA 71-86

Table 2
Reproduction Data
(Mice)

Date: October 5, 1973

Laboratory No. 1765 m

Group:	341	342	343	344	345	346
Dose (mg/kg):	Sham	Aspirin**	16.0	74.3	345.0	1600.0
Pregnancies						
Total No.	22	19	22	22	24	23
Died or Aborted (before Day 17)	0	0	0	0	0	1
To term (on Day 17)	22	19	22	22	24	22
Live Litters						
Total No.*	21	19	22	21	24	21
Implant Sites						
Total No.	251	240	263	283	265	267
Average/dam*	11.4	12.6	12.0	12.9	11.0	12.1
Resorptions						
Total No.*	19	8	5	12	21	14
Dams with 1 or more sites resorbed	6	5	4	2	9	7
Dams with all sites resorbed	1	--	--	1	--	1
Per cent partial resorptions	27.3	26.3	18.2	9.09	37.5	31.8
Per cent complete resorptions	4.55	--	--	4.55	--	4.55
Live Fetuses						
Total No.	229	224	255	268	243	250
Average/dam*	10.4	11.8	11.6	12.2	10.1	11.4
Sex ratio (M/F)	1.16	1.07	0.90	1.00	0.94	1.02
Dead Fetuses						
Total*	3	8	3	3	1	3
Dams with 1 or more dead	2	6	2	3	1	3
Dams with all dead	--	--	--	--	--	--
Per cent partial dead	9.09	31.6	9.09	13.6	4.17	13.6
Per cent all dead	--	--	--	--	--	--
Average Fetus Weight, g	0.89	0.87	0.86	0.87	0.91	0.88

* Includes only those dams examined at term.
** Positive Control: 150.0 mg/kg

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346

Laboratory No. 1765 m

Material 71-86

Table 3

Date October 5, 1973

Summary of Skeletal Findings*

(Mice)

Findings	Group No.: 341	342	343	344	345	346
Dose (mg/kg):	Sham	Aspirin**	16.0	74.3	345.0	1600.0
Live Fetuses Examined (at term)	158/21	160/19	177/22	182/21	171/24	171/21
Sternebrae						
Incomplete oss.	25/10	28/10	30/12	34/10	14/7	21/14
Scrambled			1/1			1/1
Bipartite	11/9	9/7	10/8	9/8		8/7
Fused						
Extra					1/1	
Missing	9/7	11/5	31/13	25/6	19/7	9/7
Other						
Ribs						
Incomplete oss.						
Fused/split						
Wavy						
Less than 12						
More than 13	41/14	30/12	44/17	42/15	34/16	53/19
Other						
Vertebrae						
Incomplete oss.	3/3	1/1	7/7	1/1	6/3	2/1
Scrambled						
Fused						
Extra ctrs. oss.						
Scoliosis						
Tail defects						
Other						
Skull						
Incomplete closure			1/1		1/1	1/1
Missing						
Craniostosis						
Other; facial bones, inc.	1/1					
Extremities						
Incomplete oss.	1/1	1/1	4/4		2/1	1/1
Missing						
Extra						
Miscellaneous						
Hyoid; missing	23/14	23/11	31/14	32/12	42/14	30/12
Hyoid; reduced	23/13	4/4	16/11	25/14	14/11	21/14

* Numerator=Number of fetuses affected; Denominator=Number of litters affected.

** Positive control: 150.0 mg/kg

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346 Date October 5, 1973

Material FDA 71-86 Laboratory No. 1765 m

Table 3-a

Summary of Soft Tissue Abnormalities

(Mice)

Group	Material	Dose Level mg/kg	Dam	Number of Pups	Description
342	Aspirin*	150.0	A 6102	1	Gastroschisis

*Positive Control: 150.0 mg/kg

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346

Species Mice

Date October 5, 1973

Laboratory No. 1765 m

Table 4

Average Body Weights*

Group	Material	Dose Level	Day 0	Day 6	Day 11	Day 15	Day 17**
		mg/kg	g	g	g	g	g
341	Sham	0.0	27.7	30.6	34.5	41.1	46.8 (22)
342	Aspirin***	150.0	28.7	31.9	35.0	43.4	50.2 (19)
343	FDA 71-86	16.0	29.6	33.1	35.9	43.9	50.8 (22)
344	FDA 71-86	74.3	32.3	34.6	38.0	47.4	53.7 (22)
345	FDA 71-86	345.0	29.5	32.2	35.7	44.6	50.8 (24)
346	FDA 71-86	1600.0	29.0	31.0	35.4	44.8	50.9 (22)

* Of pregnant dams
** Number of surviving dams in parentheses (c.f. Table 1)
*** Positive control: 150.0 mg/kg

Appendix I

Teratology Study in Mice

Virgin adult female albino CD-1 outbred mice were gang-housed in disposable plastic cages in temperature and humidity-controlled quarters with free access to food and fresh tap water. They were mated with young adult males, and observation of the vaginal sperm plug was considered Day 0 of gestation. Beginning on Day 6 and continuing daily through Day 15 of gestation, the females were dosed with the indicated dosages by oral intubation; the controls were sham treated.

Body weights were recorded on Days 0, 6, 11, 15, and 17 of gestation. All animals were observed daily for appearance and behavior with particular attention to food consumption and weight, in order to rule out any abnormalities which may have occurred as a result of anorexic effects in the pregnant female animal.

On Day 17 all dams were subjected to Caesarean section under surgical anesthesia, and the numbers of implantation sites, resorption sites, and live and dead fetuses were recorded. The body weights of the live pups were also recorded. The urogenital tract of each dam was examined in detail for anatomical normality.

All fetuses were examined grossly for the presence of external congenital abnormalities. One-third of the fetuses of each litter underwent detailed visceral examinations employing the Wilson technique. The remaining two-thirds were cleared in potassium hydroxide (KOH), stained with alizarin red S dye and examined for skeletal defects.

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 341

Material Sham

Dose 0.0 mg/kg

Appendix II

Reproduction Data in Mice (Individual)

Date October 5, 1973

Laboratory No. 1765

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
S 6086	P	11	11		3	8		0.80	
S 6087	P	13	12		5	7	1	0.96	
S 6088	P	9	8		5	3	1	0.87	
S 6089	P	14	14		7	7		0.77	
S 6090	P	12	9	2	5	4	1	0.70	
S 6091	P	14	13		6	7	1	0.87	
S 6092	P	9	9		5	4		0.98	
S 6093	P	12	12		5	7		0.83	
S 6094	P	15	15		9	6		0.75	
S 6095	NP	0						----	
S 6096	P	13	13		9	4		0.95	
S 6097	P	14					14	----	
S 6098	P	11	11		5	6		0.92	
S 6099	P	12	12		6	6		1.05	
S 6100	P	11	11		5	6		0.96	
S 6101	P	10	10		6	4		0.96	
S 6102	P	12	12		7	5		0.89	
S 6103	P	13	12	1	9	3		0.88	
S 6104	NP	0						----	
S 6105	P	8	8		4	4		0.83	
S 6106	P	13	13		6	7		0.87	
S 6107	P	2	1		1	0	1	1.03	
S 6108	P	10	10		6	4		0.88	
S 6109	P	13	13		6	7		0.90	
S 6110	NP	0						----	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 342

Material Aspirin

Dose 150.0 mg/kg

Appendix II

Reproduction Data in Mice (Individual)

Date October 5, 1973

Laboratory No. 1765

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
A 6086	P	11	11		5	6		0.80	
A 6087	P	15	12		6	6	3	1.11	
A 6088	P	11	11		6	5		0.99	
A 6089	P	14	14		8	6		0.84	
A 6090	NP	0						----	
A 6091	P	12	11	1	4	7		0.87	
A 6092	NP	0						----	
A 6093	P	11	11		6	5		0.97	
A 6094	P	13	11	1	6	5	1	0.83	
A 6095	P	12	12		9	3		0.88	
A 6096	P	16	13	3	7	6		0.81	
A 6097	NP	0						----	
A 6098	NP	0						----	
A 6099	P	14	14		8	6		0.85	
A 6100	P	16	16		5	11		0.78	
A 6101	P	11	10		5	5	1	0.87	
A 6102	P	10	8		3	5	2	0.80	
A 6103	NP	0						----	
A 6104	P	10	10		6	4		0.84	
A 6105	P	17	15	1	8	7	1	0.72	
A 6106	P	13	12	1	3	9		0.88	
A 6107	NP	0						----	
A 6108	P	10	9	1	5	4		0.93	
A 6109	P	13	13		9	4		0.91	
A 6110	P	11	11		7	4		0.81	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 343

Material FDA 71-86

Dose 16.0 mg/kg

Appendix II

Reproduction Data in Mice (Individual)

Date October 5, 1973

Laboratory No. 1765 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 5001	NP	0						----	
M 5002	P	10	10		4	6		0.91	
M 5003	NP	0						----	
M 5004	NP	0						----	
M 5005	P	10	10		3	7		0.75	
M 5006	P	12	12		4	8		0.74	
M 5007	P	12	12		6	6		0.93	
M 5008	P	13	13		9	4		0.87	
M 5009	P	14	14		6	8		0.83	
M 5010	P	9	9		5	4		0.71	
M 5011	NP	0						----	
M 5012	P	16	14	2	8	6		0.92	
M 5013	P	16	15		4	11	1	0.84	
M 5014	P	6	6		2	4		1.34	
11 M 5015	P	11	10		4	6	1	0.79	
M 5016	P	13	13		7	6		0.85	
M 5017	P	15	15		7	8		0.75	
M 5018	P	13	11		7	4	2	0.81	
M 5019	NP	0						----	
M 5020	NP	0						----	
M 5021	P	13	13		7	6		0.89	
M 5022	P	14	14		6	8		0.80	
M 5023	P	11	10	1	3	7		0.80	
M 5024	P	11	11		7	4		0.85	
M 5025	P	14	14		6	8		0.88	
M 5026	P	10	10		5	5		0.87	
M 5027	P	10	9		5	4	1	0.84	
M 5028	P	10	10		6	4		0.87	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Appendix II

Reproduction Data in Mice (Individual)

Group 344

Material FDA 71-86

Dose 74.3 mg/kg

Date October 5, 1973

Laboratory No. 1765 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 5031	P	13	12	1	6	6		0.86	
M 5032	P	13	13		6	7		0.90	
M 5033	P	13	13		4	9		0.82	
M 5034	NP	0						----	
M 5035	NP	0						----	
M 5036	P	11	11		7	4		0.76	
M 5037	P	10					10	----	
M 5038	P	15	14	1	6	8		0.86	
M 5039	P	10	10		6	4		1.18	
M 5040	P	12	12		6	6		0.80	
M 5041	P	8	8		3	5		0.78	
M 5042	P	13	13		5	8		0.88	
M 5043									Not Assigned
M 5044	P	13	13		6	7		0.92	
M 5045	P	17	17		10	7		0.85	
M 5046	P	11	11		5	6		0.94	
M 5047	P	14	14		8	6		0.74	
M 5048	P	15	15		7	8		0.85	
M 5049	P	13	13		7	6		0.95	
M 5050	P	12	12		7	5		0.90	
M 5051	P	14	12		6	6	2	0.88	
M 5052	P	11	10	1	6	4		0.90	
M 5053	P	14	14		7	7		0.89	
M 5054	P	16	16		7	9		0.72	
M 5055	P	15	15		9	6		0.99	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 345

Material FDA 71-86

Dose 345.0 mg/kg

Appendix II

Reproduction Data in Mice (Individual)

Date October 5, 1973

Laboratory No. 1765 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 5061	P	11	11		4	7		0.83	
M 5062	P	13	11		7	4	2	0.93	
M 5063	P	11	11		5	6		0.82	
M 5064	P	9	9		6	3		0.94	
M 5065	P	9	9		3	6		0.81	
M 5066	P	12	12		6	6		0.84	
M 5067	P	9	9		4	5		0.75	
M 5068	P	11	11		7	4		1.00	
M 5069	P	8	8		4	4		0.67	
M 5070	P	11	11		8	3		1.28	
M 5071	P	9	9		5	4		0.75	
M 5072	P	5	3		0	3	2	1.19	
M 5073	NP	0						----	
M 5074	P	10	8		3	5	2	1.35	
M 5075	P	11	11		3	8		1.18	
M 5076	P	13	12		7	5	1	0.87	
M 5077	P	15	11		4	7	4	0.77	
M 5078	P	12	12		5	7		0.79	
M 5079	P	15	12		4	8	3	0.84	
M 5080	P	11	11		5	6		0.75	
M 5081	P	14	14		7	7		0.84	
M 5082	P	12	10		6	4	2	1.00	
M 5083	P	9	8	1	4	4		0.91	
M 5084	P	12	10		5	5	2	0.88	
M 5085	P	13	10		6	4	3	0.94	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 346

Material FDA 71-86

Dose 1600.0 mg/kg

Appendix II

Reproduction Data in Mice (Individual)

Date October 5, 1973

Laboratory No. 1765 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 5091	P	14	13		6	7	1	0.93	
M 5092	P	12	11		5	6	1	0.82	
M 5093	P	11	10	1	5	5		0.97	
M 5094	NP	0						----	
M 5095	P	12	12		7	5		0.86	
M 5096	P	10	10		--	--		----	Aborted
M 5097	NP	0						----	
M 5098	NP	0						----	
M 5099	P	8					8	----	
M 5100	P	9	9		4	5		0.87	
M 5101	P	11	11		3	8		0.92	
M 5102	P	16	15		7	8	1	0.85	
M 5103	P	13	13		6	7		0.84	
M 5104	NP	0						----	
M 5105	P	13	13		5	8		0.79	
M 5106	P	14	14		7	7		0.85	
M 5107	NP	0						----	
M 5108	P	11	10		5	5	1	0.91	
M 5109	P	12	11		6	5	1	0.82	
M 5110	P	10	10		7	3		0.93	
M 5111	P	14	14		10	4		0.97	
M 5112	NP	0						----	
M 5113	P	12	12		6	6		0.90	
M 5114	P	11	10	1	5	5		0.86	
M 5115	P	14	14		7	7		0.94	
M 5116	P	11	11		8	3		0.98	
M 5117	P	11	10		4	7	1	0.79	
M 5118	P	16	15	1	8	7		0.89	
M 5119	P	12	12		6	6		0.89	
M 5120	NP	0						----	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG
Research LABORATORIES, INC.

WAVERLY DIVISION
Route 17
P.O. Box 107
Waverly, New York 14892
(607) 565-2931

FINAL REPORT

Submitted to: DHEW/Public Health Service
Food and Drug Administration CA-272
5600 Fishers Lane-Room 5C-13
Rockville, Maryland 20852

Date November 5, 1973

Laboratory No. 1766 m
Contract No. FDA 71-260

Sample: Fine white powdered material

Marking: FDA 71-86 (Calcium sulfate)

Examination Requested: Teratologic evaluation of FDA 71-86 in rats

Procedure: See Appendix I

Results: See Tables 1 through 4 and Appendix II

Conclusion:

On the basis of the data presented herein, the following conclusion appears to be warranted:

"The administration of up to 1600 mg/kg (body weight) of the test material to pregnant rats for 10 consecutive days had no clearly discernible effect on nidation or on maternal or fetal survival. The number of abnormalities seen in either soft or skeletal tissues of the test groups did not differ from the number occurring spontaneously in the sham-treated controls."

FOOD and DRUG RESEARCH LABORATORIES, INC.

Kenneth Morgareidge

Kenneth Morgareidge, Ph.D.
Vice President

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups: 341 through 346

Material : FDA 71-86

Date: October 5, 1973

Laboratory No. : 1766 m

Table 1

Fate Summary
(Rats)

Group	Material	Dose** mg/kg	Total Mated	Total Pregnant	Surviving at Term Total	Surviving at Term Pregnant[1]
341	Sham	0.0	25	25	25	25
342	Aspirin*	250.0	25	23	25	23
343	FDA 71-86	16.0	25	21	25	21
344	FDA 71-86	74.3	25	23	25	23
345	FDA 71-86	345.0	25	23	25	23
346	FDA 71-86	1600.0	25	21	25	21

* Positive Control : 250.0 mg/kg
** Administered as a water solution (See Appendix I)
1) Includes all dams examined at term

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group: 341 through 346

Material: FDA 71-86

Date: October 5, 1973

Laboratory No. 1766 m

Table 2
Reproduction Data
(Rats)

Group:	341	342	343	344	345	346
Dose (mg/kg):	Sham	Aspirin**	16.0	74.3	345.0	1600.0
Pregnancies						
Total No.	25	23	21	23	23	21
Died or Aborted (before Day 20)	0	0	0	0	0	0
To term (on Day 20)	25	23	21	23	23	21
Live Litters						
Total No.*	25	18	21	23	23	21
Implant Sites						
Total No.	279	231	229	270	253	233
Average/dam*	11.2	10.0	10.9	11.7	11.0	11.1
Resorptions						
Total No.*	4	62	4	7	7	4
Dams with 1 or more sites resorbed	3	11	3	3	2	3
Dams with all sites resorbed	--	4	--	--	--	--
Per cent partial resorptions	12.0	47.8	14.3	13.0	8.70	14.3
Per cent complete resorptions	--	17.4	--	--	--	--
Live Fetuses						
Total No.	275	168	224	263	246	229
Average/dam*	11.0	7.30	10.7	11.4	10.7	10.9
Sex ratio (M/F)	1.07	1.06	0.87	1.07	1.18	0.75
Dead Fetuses						
Total*	--	1	1	--	--	--
Dams with 1 or more dead	--	1	1	--	--	--
Dams with all dead	--	1	--	--	--	--
Per cent partial dead	--	4.35	4.76	--	--	--
Per cent all dead	--	4.35	--	--	--	--
Average Fetus Weight, g	3.68	2.39	3.92	3.94	3.77	4.04

* Includes only those dams examined at term.
** Positive Control: 250.0 mg/kg

17

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346 | Laboratory No. 1766 m

Table 3

Material FDA 71-86 | Date October 5, 1973

Summary of Skeletal Findings*

(Rats)

Findings — Group No.:	341	342	343	344	345	346
Dose (mg/kg):	Sham	Aspirin**	16.0	74.3	345.0	1600.0
Live Fetuses Examined (at term)	191/25	120/18	155/21	185/23	172/23	160/21
Sternebrae						
Incomplete oss.	86/22	44/15	37/14	32/12	56/19	23/11
Scrambled						
Bipartite	1/1	2/2	2/2	3/3	1/1	
Fused						
Extra						
Missing	34/17	103/18	16/8	5/4	28/13	7/5
Other						
Ribs						
Incomplete oss.		15/9				1/1
Fused/split						
Wavy	22/10	41/16	14/9	21/10	27/11	28/12
Less than 12		1/1				
More than 13		95/17	1/1	3/3		5/2
Other						
Vertebrae						
Incomplete oss.	24/14	76/18	17/9	8/6	30/13	13/7
Scrambled						
Fused						
Extra ctrs. oss.						
Scoliosis		1/1				
Tail defects						
Other ; spina bifida		1/1				
Skull						
Incomplete closure	36/13	54/17	20/9	29/14	52/17	28/13
Missing		2/2				
Craniostosis						
Other						
Extremities						
Incomplete oss.		3/3				
Missing						
Extra						
Miscellaneous						
Hyoid; missing	26/14	57/17	19/9	15/8	15/9	12/7
Hyoid; reduced	17/12	8/4	12/6	13/8	23/10	12/7

* Numerator=Number of fetuses affected; Denominator=Number of litters affected.

** Positive control: 250.0 mg/kg

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346 Date October 5, 1973

Material FDA 71-86 Laboratory No. 1766 m

Table 3-a

Summary of Soft Tissue Abnormalities

(Rats)

Group	Material	Dose Level mg/kg	Dam	Number of Pups	Description
342	Aspirin*	250.0	A 7088	1	Meningoencephalocele
			A 7093	3	Encephalomyelocele; umbilical hernia
				1	Hydrocephalus; exophthalmos; gastroschisis
			A 7107	1	Meningoencephalocele; umbilical hernia
343	FDA 71-86	16.0	M 6008	1	Umbilical hernia
344	FDA 71-86	74.3	M 6031	1	Umbilical hernia
345	FDA 71-86	345.0	M 6079	1	Umbilical hernia

*Positive Control: 250.0 mg/kg

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346

Species Rats

Date October 5, 1973

Laboratory No. 1766 m

Table 4

Average Body Weights*

Group	Material	Dose Level	Day 0	Day 6	Day 11	Day 15	Day 20**
		mg/kg	g	g	g	g	g
341	Sham	0.0	232	252	268	295	353 (25)
342	Aspirin***	250.0	226	247	253	268	311 (23)
343	FDA 71-86	16.0	229	252	269	292	359 (21)
344	FDA 71-86	74.3	224	243	261	282	353 (23)
345	FDA 71-86	345.0	225	242	259	279	349 (23)
346	FDA 71-86	1600.0	223	243	259	282	348 (21)

* Of pregnant dams
** Number of surviving dams in parentheses (c.f. Table 1)
*** Positive control: 250.0 mg/kg

20<

Appendix I

Teratology Study in Rats

Virgin adult female albino rats (Wistar derived stock) were individually housed in mesh bottom cages in temperature and humidity-controlled quarters with free access to food and fresh tap water. They were mated with young adult males, and observation of the vaginal sperm plug was considered Day 0 of gestation. Beginning on Day 6 and continuing daily through Day 15 of gestation, the females were dosed with the indicated dosages by oral intubations. The controls were sham treated with the vehicle at a level equivalent to the group receiving the highest test dose. The test material was prepared and doses calculated according to the following table:

Dosage (mg/kg)	Dose (ml/kg)	Concentration (mg/ml)
≤ 250	1	≤ 250
251 - 500	2	125 - 250
501 - 750	3	133 - 250
751 - 1000	4	187 - 250
1001 - 1250	5	200 - 250
1251 - 1500	6	208 - 250
1501 - 1600	6.4	235 - 250

Body weights were recorded on Days 0, 6, 11, 15, and 20 of gestation. All animals were observed daily for appearance and behavior with particular attention to food consumption and weight, in order to rule out any abnormalities which may have occurred as a result of anorexic effects in the pregnant female animal.

On Day 20 all dams were subjected to Caesarean section under surgical anesthesia, and the numbers of implantation sites, resorption sites, and live and dead fetuses were recorded. The body weights of the live pups were also recorded. The urogenital tract of each dam was examined in detail for anatomical normality.

All fetuses were examined grossly for the presence of external congenital abnormalities. One-third of the fetuses of each litter underwent detailed visceral examinations employing the Wilson technique. The remaining two-thirds were cleared in potassium hydroxide (KOH), stained with alizarin red S dye and examined for skeletal defects.

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 341

Material Sham

Dose 0.0 mg/kg

Appendix II

Reproduction Data in Rats (Individual)

Date October 5, 1973

Laboratory No. 1766

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
S 7086	P	11	11		6	5		3.59	
S 7087	P	14	14		6	8		3.42	
S 7088	P	10	10		4	6		3.66	
S 7089	P	10	10		5	5		3.51	
S 7090	P	13	13		7	6		3.70	
S 7091	P	12	12		3	9		3.89	
S 7092	P	12	12		8	4		3.73	
S 7093	P	10	10		5	5		3.81	
S 7094	P	12	12		7	5		3.73	
S 7095	P	12	12		8	4		3.62	
S 7096	P	14	14		8	6		3.36	
S 7097	P	12	12		4	8		3.87	
S 7098	P	9	9		5	4		3.45	
S 7099	P	10	10		6	4		3.28	
S 7100	P	6	6		3	3		4.12	
S 7101	P	12	12		6	6		3.70	
S 7102	P	10	10		5	5		3.74	
S 7103	P	13	13		8	5		3.63	
S 7104	P	15	13		9	4	2	3.64	
S 7105	P	12	11		4	7	1	3.48	
S 7106	P	9	8		6	2	1	4.06	
S 7107	P	5	5		2	3		4.23	
S 7108	P	13	13		4	9		3.49	
S 7109	P	12	12		6	6		3.87	
S 7110	P	11	11		7	4		3.45	

* P = Pregnant; NP = Not Pregnant

23^

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 342

Material Aspirin

Dose 250.0 mg/kg

Appendix II

Reproduction Data in Rats (Individual)

Date October 5, 1973

Laboratory No. 1766

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
A 7086	P	10					10	----	
A 7087	P	13					13	----	
A 7088	P	11	9		3	6	2	2.14	
A 7089	P	9	2		0	2	7	1.87	
A 7090	P	11	11		5	6		2.45	
A 7091	P	14	13		9	4	1	2.70	
A 7092	P	14	14		7	7		2.84	
A 7093	P	10	6		2**	1**	4	1.31	
A 7094	P	12	12		4	8		2.25	
A 7095	P	12					12	----	
A 7096	P	11	11		7	4		2.72	
A 7097	P	8	7		4	3	1	2.31	
A 7098	P	4	4		1	3		2.51	
A 7099	P	14	14		7	7		2.61	
A 7100	P	12	12		7	5		3.06	
A 7101	P	12	12		4	8		2.14	
A 7102	NP	0						----	
A 7103	NP	0						----	
A 7104	P	8	8		4	4		2.73	
A 7105	P	10	10		6	4		2.27	
A 7106	P	13	12		9	3	1	2.48	
A 7107	P	6	3		1	2	3	2.22	
A 7108	P	8					8	----	
A 7109	P	1		1				----	
A 7110	P	8	8		5	3		2.37	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 343

Material FDA 71-86

Dose 16.0 mg/kg

Appendix II

Reproduction Data in Rats (Individual)

Date October 5, 1973

Laboratory No. 1766 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 6001	P	12	12		4	8		3.57	
M 6002	P	11	9		5	4	2	4.21	
M 6003	P	14	13		4	9	1	3.93	
M 6004	P	13	13		9	4		3.57	
M 6005	P	15	15		2	13		3.08	
M 6006	P	9	9		3	6		3.25	
M 6007	P	12	12		9	3		3.57	
M 6008	P	14	14		8	6		4.04	
M 6009	NP	0						-----	
M 6010	NP	0						-----	
M 6011	P	1	1		0	1		2.50	
M 6012	P	9	9		3	6		6.23	
M 6013	P	12	12		8	4		3.71	
M 6014	P	11	11		6	5		3.59	
M 6015	P	14	13		5	8	1	3.87	
M 6016	P	10	10		5	5		3.86	
M 6017	P	10	10		6	4		3.73	
M 6018	P	14	14		4	10		3.60	
M 6019	P	10	10		8	2		3.76	
M 6020	NP	0						-----	
M 6021	NP	0						-----	
M 6022	P	2	2		1	1		5.03	
M 6023	P	12	12		8	4		5.16	
M 6024	P	12	12		2	10		4.07	
M 6025	P	12	11	1	4	7		3.99	

* P = Pregnant; NP = Not Pregnant

25<

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 344

Material FDA 71-86

Dose 74.3 mg/kg

Appendix II

Reproduction Data in Rats (Individual)

Date October 5, 1973

Laboratory No. 1766 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 6031	P	13	13		9	4		3.81	
M 6032	P	13	13		8	5		3.76	
M 6033	P	13	13		8	5		3.73	
M 6034	P	11	8		4	4	3	4.09	
M 6035	P	10	7		4	3	3	3.91	
M 6036	P	13	13		7	6		3.95	
M 6037	P	13	13		3	10		3.86	
M 6038	P	11	11		6	5		3.60	
M 6039	P	11	11		5	6		5.28	
M 6040	P	12	12		7	5		3.54	
M 6041	P	13	13		6	7		3.48	
M 6042	NP	0						----	
M 6043	P	13	13		6	7		3.97	
M 6044	P	5	4		2	2	1	4.10	
M 6045	P	11	11		7	4		3.56	
M 6046	P	15	15		7	8		3.63	
M 6047	NP	0						----	
M 6048	P	13	13		7	6		3.76	
M 6049	P	11	11		7	4		3.43	
M 6050	P	14	14		8	6		3.96	
M 6051	P	10	10		4	6		5.44	
M 6052	P	7	7		3	4		4.04	
M 6053	P	11	11		6	5		3.84	
M 6054	P	13	13		4	9		3.76	
M 6055	P	14	14		8	6		4.13	

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 345

Material FDA 71-86

Dose 345.0 mg/kg

Appendix II

Reproduction Data in Rats (Individual)

Date October 5, 1973

Laboratory No. 1766 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 6061	P	9	8		6	2	1	4.42	
M 6062	P	11	11		8	3		3.27	
M 6063	P	11	5		2	3	6	4.52	
M 6064	NP	0						-----	
M 6065	P	12	12		5	7		3.33	
M 6066	P	11	11		5	6		3.69	
M 6067	P	10	10		5	5		3.51	
M 6068	P	10	10		4	6		3.23	
M 6069	P	10	10		5	5		3.84	
M 6070	P	10	10		4	6		4.09	
M 6071	P	7	7		3	4		4.14	
M 6072	P	15	15		12	3		3.57	
M 6073	P	12	12		10	2		3.91	
M 6074	P	13	13		6	7		3.63	
M 6075	P	10	10		5	5		3.48	
M 6076	P	17	17		10	7		3.50	
M 6077	P	13	13		9	4		3.96	
M 6078	NP	0						-----	
M 6079	P	12	12		7	5		3.80	
M 6080	P	10	10		5	5		3.75	
M 6081	P	12	12		5	7		3.48	
M 6082	P	10	10		7	3		3.79	
M 6083	P	9	9		3	6		3.90	
M 6084	P	8	8		2	6		3.95	
M 6085	P	11	11		5	6		3.94	

* P = Pregnant; NP = Not Pregnant

27^

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 346

Material FDA 71-86

Dose 1600.0 mg/kg

Appendix II

Reproduction Data in Rats (Individual)

Date October 5, 1973

Laboratory No. 1766 m

Dam No.	Fate*	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 6091	P	11	11		6	5		3.99	
M 6092	P	10	10		2	8		3.67	
M 6093	P	13	12		5	7	1	3.76	
M 6094	P	11	11		6	5		3.68	
M 6095	P	15	13		5	8	2	3.44	
M 6096	P	12	12		5	7		3.51	
M 6097	NP	0						----	
M 6098	P	2	2		0	2		4.04	
M 6099	P	10	10		5	5		3.67	
M 6100	P	13	13		5	8		3.60	
M 6101	P	12	12		7	5		5.29	
M 6102	NP	0						----	
M 6103	P	10	10		4	6		3.65	
M 6104	P	12	12		7	5		3.76	
M 6105	P	12	12		5	7		3.42	
M 6106	P	9	9		4	5		4.64	
M 6107	P	13	13		6	7		3.60	
M 6108	P	10	10		6	4		3.54	
M 6109	NP	0						----	
M 6110	P	14	14		7	7		5.42	
M 6111	P	12	12		1	11		5.47	
M 6112	NP	0						----	
M 6113	P	10	10		5	5		5.55	
M 6114	P	10	10		3	7		3.70	
M 6115	P	12	11		4	7	1	3.51	

* P = Pregnant; NP = Not Pregnant

28<

FDRL

FOOD AND DRUG Research LABORATORIES, INC.

WAVERLY DIVISION
Route 17
P.O. Box 107
Waverly, New York 14892
(607) 565-2931

FINAL REPORT

Submitted to: DHEW/Public Health Service
Food and Drug Administration CA-272
5600 Fishers Lane-Room 5C-13
Rockville, Maryland 20852

Date February 19, 1974

Laboratory No. 1767 m
Contract No. FDA 71-260

Sample: Fine white powdered material

Marking: FDA 71-86 (Calcium sulfate)

Examination Requested: Teratologic evaluation of FDA 71-86 in rabbits

Procedure: (See Appendix I)

Results: See Tables 1 through 4 and Appendix II

Conclusion:

On the basis of the data presented herein, the following conclusion appears to be warranted:

"The administration of up to 1600 mg/kg (body weight) of the test material to pregnant rabbits for 13 consecutive days had no clearly discernible effect on nidation or on maternal or fetal survival. The number of abnormalities seen in either soft or skeletal tissues of the test groups did not differ from the number occurring spontaneously in the sham-treated controls."

FOOD and DRUG RESEARCH LABORATORIES, INC.

Kenneth Morgareidge

Kenneth Morgareidge, Ph.D.
Director

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups: 341 through 346

Material : FDA 71-86

Date: January 18, 1974

Laboratory No. : 1767 m

Table 1

Fate Summary

(Rabbits)

Group	Material	Dose * mg/kg	Total Mated	Total Pregnant	Surviving at Term Total	Surviving at Term Pregnant[1]
341	Sham	0.0	18	13	18	13
342	6-AN*	2.5	20	10	19	10
343	FDA 71-86	16.0	22	14	19	11
344	FDA 71-86	74.3	22	13	21	13
345	FDA 71-86	345.0	20	13	19	12
346	FDA 71-86	1600.0	20	14	15	11

* Positive Control : 2.5 mg/kg of 6-aminonicotinamide dosed on Day 9

** Administered as a water solution. (See Appendix I)

1) Includes all dams examined at term

30<

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group : 341 through 346

Material : FDA 71-86

Table 2

Reproduction Data

(Rabbits)

Date : January 18, 1974

Laboratory No. : 1767 m

Group:	341	342	343	344	345	346
Dose (mg/kg):	Sham	6-AN**	16.0	74.3	345.0	1600.0
Pregnancies						
Total No.	13	10	14	13	13	14
Died or Aborted (before Day 29)	0	0	3	0	1	3
To term (on Day 29)	13	10	11	13	12	11
Corpora Lutea						
Total No.	174	122	195	173	134	139
Average/dam mated	9.67	6.42	9.29	8.65	7.05	7.72
Live Litters						
Total No.*	12	10	11	13	10	10
Implant Sites						
Total No.	69	56	60	70	68	62
Average/dam*	5.31	5.60	5.45	5.38	5.67	5.64
Resorptions						
Total No.*	4	2	4	7	9	4
Dams with 1 or more sites resorbed	3	1	3	3	6	1
Dams with all sites resorbed	1	--	--	--	2	1
Per cent partial resorptions	23.1	10.0	27.3	23.1	50.0	9.09
Per cent complete resorptions	7.69	--	--	--	16.7	9.09
Live Fetuses						
Total No.	65	54	56	63	59	58
Average/dam*	5.00	5.40	5.09	4.85	4.92	5.27
Sex ratio (M/F)	0.86	0.74	1.33	1.30	1.36	1.42
Dead Fetuses						
Total No.*	--	--	--	--	--	--
Dams with 1 or more dead	--	--	--	--	--	--
Dams with all dead	--	--	--	--	--	--
Per cent partial dead	--	--	--	--	--	--
Per cent all dead	--	--	--	--	--	--
Average Fetus Weight, g	38.2	33.8	37.8	38.2	39.9	42.4

* Includes only those dams examined at term.

** Positive Control : 2.5 mg/kg of 6-aminonicotinamide dosed on Day 9

31 ^

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346 Laboratory No. 1767 m

Table 3

Material FDA 71-86 Date January 18, 1974

Summary of Skeletal Findings*

(Rabbits)

Findings Group No.:	341	342	343	344	345	346
Dose (mg/kg):	Sham	6-AN**	16.0	74.3	345.0	1600.0
Live Fetuses Examined (at term)	65/12	53/10[a]	56/11	63/13	59/10	58/10
Sternebrae						
Incomplete oss.			2/1			
Scrambled						
Bipartite				1/1		1/1
Fused		1/1				1/1
Extra						
Missing						
Other						
Ribs						
Incomplete oss.						
Fused/split		2/1				
Wavy						
Less than 12						
More than 13						
Other						
Vertebrae						
Incomplete oss.						
Scrambled		5/1				
Fused						
Extra ctrs. oss.						
Scoliosis		1/1				
Tail defects		10/3				1/1
Other						
Skull						
Incomplete closure	1/1					
Missing						
Craniostosis			2/1			
Other						
Extremities						
Incomplete oss.				6/1		
Missing						
Extra						
Miscellaneous						

* Numerator=Number of fetuses affected; Denominator=Number of litters affected.

** Positive control: 2.5 mg/kg of 6-aminonicotinamide dosed on Day 9

a [illegible]

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346 Date January 18, 1974

Material FDA 71-86 Laboratory No.1767 m

Table 3-a

Summary of Soft Tissue Abnormalities

(Rabbits)

Group	Material	Dose Level mg/kg	Dam	Number of Pups	Description
342	6-AN*	2.5	Z 7640	2	Medial rotation of hind limbs
343	FDA 71-86	16.0	M 7081	1	Fetal monster

*Positive Control: 2.5 mg/kg of 6-aminonicotinamide dosed on Day 9

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Groups 341 through 346

Species Rabbits

Date January 18, 1974

Laboratory No. 1767 m

Table 4

Average Body Weights*

Group	Material	Dose Level	Day 0	Day 6	Day 12	Day 18	Day 29**
		mg/kg	kg				
341	Sham	0.0	2.23	2.32	2.40	2.48	2.59 (13)
342	6-AN***	2.5	1.86	1.94	2.03	2.08	2.18 (10)
343	FDA 71-86	16.0	2.21	2.27	2.34	2.45	2.53 (11)
344	FDA 71-86	74.3	2.03	2.08	2.15	2.23	2.34 (13)
345	FDA 71-86	345.0	2.19	2.29	2.35	2.48	2.61 (12)
346	FDA 71-86	1600.0	2.10	2.19	2.21	2.32	2.42 (11)

* Of pregnant dams
** Number of surviving dams in parentheses (c.f. Table 1)
*** Positive control: 2.5 mg/kg of aminonicotinamide dosed on Day 9

34<

Appendix I

Teratology Study in Rabbits

Virgin, adult, Dutch-belted female rabbits were individually housed in mesh bottom cages in temperature and humidity-controlled quarters with free access to food and fresh tap water. On Day 0, each doe was given an injection of 0.4 ml of human chorionic gonadotropin (400 IU) via the marginal ear vein. Three hours later, each doe was inseminated artificially with 0.3 ml of diluted semen from a proven donor buck using approximately 20×10^6 motile sperm according to the procedure described by Vogin et al (Pharmacologist 11, 282 (1969)). Beginning on Day 6 and continuing daily through Day 18 the females were dosed with the indicated dosages by oral intubation. The controls were sham treated with the vehicle at a level equivalent to the group receiving the highest test dose. The test material was prepared and doses calculated according to the following table:

Dosage (mg/kg)	Dose (ml/kg)	Concentration (mg/ml)
≦ 250	1	≦ 250
251 - 500	2	125 - 250
501 - 750	3	133 - 250
751 - 1000	4	187 - 250
1001 - 1250	5	200 - 250
1251 - 1500	6	208 - 250
1501 - 1600	6.4	235 - 250

Body weights were recorded on Days 0, 6, 12, 18, and 29 of gestation. All animals were observed daily for appearance and behavior, with particular attention to food consumption and body weight in order to rule out any abnormalities which may have occurred as a result of anorexic effects in the pregnant female animal.

On Day 29 all does were subjected to Caesarean section under surgical anesthesia, and the numbers of corpora lutea, implantation sites, resorption sites and live and dead fetuses were recorded. Body weights of the live pups were also recorded. The urogenital tract of each animal was examined in detail for normality. In addition all fetuses underwent a detailed gross examination for the presence of external congenital abnormalities. The live fetuses of each litter were then placed in an incubator for 24 hours for the evaluation of neonatal survival. All surviving pups were sacrificed, and all pups examined for visceral abnormalities (by dissection). All fetuses were then cleared in potassium hydroxide (KOH), stained with alizarin red S dye and examined for skeletal defects.

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 341

Material Sham

Dose 0.0 mg/kg

Appendix II

Reproduction Data in Rabbits (Individual)

Date January 18, 1974

Laboratory No. 1767

Dam No.	Fate*	Corpora Lutea	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
S 7621	NP	0	0						----	
S 7622	NP	1	0						----	
S 7623	P	12	2	2		1	1		32.2	Two Neonatal Deaths
S 7624	NP	0	0						----	
S 7625	P	6	6	6		1	5		24.7	One Neonatal Death
S 7626	P	9	4	4		3	1		45.2	
S 7627	P	13	5	5		3	2		37.0	
S 7628	P	11	5	5		2	3		43.0	
S 7629	P	16	11	11		5	6		35.4	One Neonatal Death
S 7630	P	15	8	8		6	2		33.9	One Neonatal Death
S 7631	P	13	7	7		4	3		40.8	
S 7632	P	12	8	6		1	5	2	31.6	
S 7633	NP	12	0						----	
S 7634	P	16	1					1	----	
S 7635	P	10	5	4		1	3	1	37.4	
S 7636	P	11	2	2		1	1		49.5	
S 7637	P	14	5	5		2	3		47.8	
S 7640	NP	3	0						----	

37

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 342

Material 6-AN

Dose 2.5 mg/kg

Appendix II

Reproduction Data in Rabbits (Individual)

Date January 18, 1974

Laboratory No. 1767

Dam No.	Fate*	Corpora Lutea	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
Z 7621	P	9	5	5		1	4		26.5	Two Neonatal Deaths
Z 7622	P	8	6	6		3	3		21.2	One Neonatal Death
Z 7623	NP	--**	0						----	Died Day 18
Z 7624	NP	0	0						----	
Z 7625	NP	0	0						----	
Z 7626	NP	0	0						----	
Z 7627	NP	6	0						----	
Z 7628	NP	3	0						----	
Z 7629	P	11	8	8		3	5		34.0	
Z 7630	P	9	7	7		3	4		33.4	
Z 7631	P	18	5	3		3	0	2	42.1	
Z 7632	P	9	4	4		2	2		38.8	
Z 7633	NP	10	0						----	
Z 7634	NP	0	0						----	
Z 7635	P	9	6	6		0	6		31.9	Two Neonatal Deaths
Z 7636	NP	2	0						----	
Z 7637	P	10	6	6		4	2		40.0	
Z 7638	NP	1	0						----	
Z 7639	P	7	5	5		2	3		33.4	
Z 7640	P	10	4	4		2	2		36.9	One Neonatal Death

38

* P = Pregnant; NP = Not Pregnant
** Not Recorded

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 343

Material FDA 71-86

Dose 16.0 mg/kg

Appendix II

Reproduction Data in Rabbits (Individual)

Date January 18, 1974

Laboratory No. 1767 m

Dam No.	Fate*	Corpora Lutea	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 7001	P	11	2	2		1	1		40.5	
M 7002	NP	0	0						----	
M 7003	NP	0	0						----	
M 7004	P	10	7	7		4	3		20.6	
M 7005	NP	0	0						----	
M 7006	NP	5	0						----	
M 7007	NP	10	0						----	
M 7008	P	12	6	4		2	2	2	42.7	
M 7009	P	24	4	4		2	2		43.6	
M 7010	P	7	4					4	----	Died Day 16
M 7011	P	18	3	2		1	1	1	45.1	
M 7012	P	11	9	--		--	--		----	Aborted Day 27
M 7013	P	--	--	--		--	--		----	Aborted Day 13
M 7014	P	6	7	7		3	4		34.0	
M 7015	NP	5	0						----	
M 7016	NP	11	0						----	
M 7017	P	11	6	6		3	3		37.0	
M 7018	P	12	4	4		3	1		43.9	
M 7019	NP	7	0						----	
M 7020	P	10	4	4		2	2		36.7	
M 7081	P	13	11	11		7	4		37.0	Two Neonatal Deaths
M 7082	P	12	6	5		4	1	1	34.7	

39

* P = Pregnant; NP = Not Pregnant

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 344

Material FDA 71-86

Dose 74.3 mg/kg

Appendix II

Reproduction Data in Rabbits (Individual)

Date January 18, 1974

Laboratory No. 1767 m

Dam No.	Fate*	Corpora Lutea	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 7021	NP	0	0						----	
M 7022	NP	7	0						----	
M 7023	NP	0	0						----	
M 7024	NP	0	0						----	
M 7025	NP	--**	0						----	Died Day 16
M 7026	P	12	7	7		3	4		21.6	
M 7027	P	6	2	2		1	1		43.5	
M 7028	P	11	7	7		4	3		36.2	One Neonatal Death
M 7029	NP	16	0						----	
M 7030	NP	8	0						----	
M 7031	P	14	4	4		2	2		40.4	Four Neonatal Deaths
M 7032	P	8	6	6		4	2		38.0	Three Neonatal Deaths
M 7033	P	13	7	7		3	4		35.7	
M 7034	P	12	5	2		1	1	3	35.9	
M 7035	NP	8	0						----	
M 7036	NP	1	0						----	
M 7037	P	10	3	3		1**	1**		40.0	
M 7038	P	--**	6	3		2	1	3	37.5	
M 7039	P	10	3	3		2	1		42.7	
M 7040	P	13	9	9		5	4		35.3	
M 7083	P	6	4	4		3	1		42.8	
M 7084	P	18	7	6		4	2	1	46.8	

40

* P = Pregnant; NP = Not Pregnant

** Not Recorded

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 345

Material FDA 71-86

Dose 345.0 mg/kg

Appendix II

Reproduction Data in Rabbits (Individual)

Date January 18, 1974

Laboratory No. 1767 m

Dam No.	Fate*	Corpora Lutea	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 7041	P	16	9	9		5	4		39.6	
M 7042	P	11	8	--		--	--		----	Died Day 16
M 7043	P	8	6	6		3	3		39.4	
M 7044	P	12	5	4		3	1	1	46.3	
M 7045	NP	7	0						----	
M 7046										Not Assigned
M 7047	NP	0	0						----	
M 7048	NP	2	0						----	
M 7049	P	8	4	4		2	2		26.3	
M 7050	P	10	3	3		2	1		40.4	
M 7051	NP	0	0						----	
M 7052	NP	0	0						----	
M 7053										Not Assigned
M 7054	P	7	3					3	----	
M 7055	P	4**	5	5		3	2		37.1	
M 7056	NP	3	0						----	
M 7057	P	13	9	9		5	4		46.9	
M 7058	P	10	8	7		4	3	1	38.6	
M 7059	P	8	7	5		3	2	2	38.3	
M 7060	P	14	8	7		4	3	1	45.9	
M 7081	NP	--***	0						----	
M 7082	P	1	1					1	----	

41

* P = Pregnant; NP = Not Pregnant
** One Ovary Not Read.
*** Not Recorded

FOOD AND DRUG RESEARCH LABORATORIES, INC.

Group 346

Material FDA 71-86

Dose 1600.0 mg/kg

Appendix II

Reproduction Data in Rabbits (Individual)

Date January 18, 1974

Laboratory No. 1747 m

Dam No.	Fate*	Corpora Lutea	Implant Sites	Fetuses Alive	Fetuses Dead	Sex M	Sex F	Resorption Sites	Average Fetus Weight (g)	Remarks
M 7061	NP	1	0						----	
M 7062	NP	5	0						----	
M 7063	P	9	5	--		--	--		----	Died Day 13
M 7064	NP	0	0						----	
M 7065	P	8	3	3		2	1		50.8	
M 7066	P	10	6	6		4	2		36.0	
M 7067	P	--	--	--		--	--		----	Aborted Day 23
M 7068	NP	0	0						----	Died Day 13
M 7069	NP	9	0						----	Died Day 29
M 7070	P	7	4	4		1	3		43.2	
M 7071	P	13	5	5		2	3		40.6	
M 7072	P	8	4	4		3	1		40.2	One Neonatal Death
M 7073	P	9	9	9		4	5		34.5	
M 7074	NP	0	0						----	
M 7075	P	18	8	8		5	3		45.5	
M 7076	P	14	6	6		5	1		48.4	
M 7077	P	8	5	5		3	2		42.0	
M 7078	P	5	4					4	----	
M 7079	P	--	--	--		--	--		----	Aborted Day 10
M 7080	P	15	8	8		5	3		42.7	

* P = Pregnant; NP = Not Pregnant

ATTACHMENT C

MEDICAL APPLICATIONS

Attachment C
Medical Applications

The NTP has removed copyrighted material (reprinted journal article) from this file:

Turner TM, Urban RM, Gitelis S, Kuo KN, Andersson GB. Radiographic and histologic assessment of calcium sulfate in experimental animal models and clinical use as a resorbable bone-graft substitute, a bone-graft expander, and a method for local antibiotic delivery. One institution's experience. J Bone Joint Surg Am. 2001;83-A Suppl 2(Pt 1):8-18. PMID: 11685848.

ATTACHMENT D1

ADDITIONAL INTRATRACHEAL TEST

26-WEEK INTRATRACHEAL TOXICITY STUDY IN RATS

CALCIUM SULPHATE ANHYDRITE WHISKER FIBERS

FINAL REPORT

Submitted to

Franklin Key Inc.
Valley Forge, Pennsylvania

HAZLETON LABORATORIES, INC.
9200 LEESBURG TURNPIKE • VIENNA, VIRGINIA • 22180

July 26, 1974

SPONSOR: Franklin Key, Inc. DATE: July 26, 1974

MATERIAL: Calcium Sulphate Anhydrite Whisker Fibers

SUBJECT: FINAL REPORT
26-Week Intratracheal Toxicity Study in Rats
Project No. 865-100

SUMMARY

One hundred fifty male albino rats were divided into six groups of 25 rats each. Group No. 1 served as a vehicle control and received sterile physiologic saline at a volume equal to all other groups. Groups No. 2 and No. 3 served as negative control (10 ml. graphite in saline) and positive control (10 mg. quartz in saline), respectively. Groups No. 4, No. 5, and No. 6 received the test material, calcium sulphate anhydrite whisker fibers in saline, at levels of 0.1 mg., 1.0 mg., and 10.0 ml., respectively. The compound was administered by intratracheal instillation in a single dose.

Criteria evaluated for compound effect were physical appearance, behavior, growth, survival, lung weights, and gross and microscopic pathology.

Interim sacrifices of five animals per group were conducted at intervals of 24 hours, one week, four weeks, and 13 weeks. The study was terminated at 26 weeks.

Treatment of test rats at dosage levels of 0.1 mg, and 1.0 mg. and subsequent observation for 26 weeks failed to elicit any biologically meaningful signs of compound-induced systemic toxicity. Observation and

examination of animals at these dosage levels according to the previously mentioned criteria revealed findings comparable with those of the vehicle and negative control animals.

Animals at the highest test level (10 mg.) displayed a statistically significant suppression of body weights in comparison to the vehicle and negative controls. In addition, lung weights and lung/body weight ratios for these animals were significantly elevated at Week 1. Microscopic evaluation of lung sections from these animals at Week 1 revealed a slightly more marked inflammatory reaction in this group than in the other test groups. This was not considered a compound effect but may have been a reaction due to a bacterial infection secondary to the stress produced by the intratracheal instillation of the material. A side effect of this reaction may have been the suppression of body weight by means of a suppressed food consumption; however, food consumption was not monitored and therefore the exact biological significance of the suppressed body weights for these animals is uncertain.

Animals treated with the positive control (quartz) revealed a higher incidence of grossly observable signs throughout the final six weeks of the study. Gross necropsy findings at 13 weeks and termination for these animals included nodules in the lungs and enlargement of the thymus and peribronchial lymph nodes. Microscopic evaluation of these tissues revealed the presence of numerous silicotic nodules in the lungs and peribronchial lymph nodes at Week 4. These conditions persisted until termination along with similar nodules in the thymus sections at 13 and 26 weeks.

During the course of the study a single animal of the vehicle control group was found dead.

INTRODUCTION

The purpose of this study is to identify, evaluate, and characterize the effects of a single intratracheal instillation of calcium sulphate anhydrite whisker fibers in male albino rats. The animals were treated on November 29, 1973 observed for 26 weeks, and terminated on May 30, 1974.

MATERIAL

Test Compound

Identification: Calcium Sulphate Anhydrite Whisker Fibers.

Description; Fine white fibers.

Receipt Date: October 17, 1973 from Franklin Key Inc.

Purity: Used as received.

Reference Compounds

Identification: Graphite Powder (Acheson No. 38).

Description: A fine black powder.

Receipt Date: October 26, 1973 from Fisher Scientific Company.

Purity: Used as received.

Identification: Min-U-Sil (5 microns).

Description: A fine white powder.

Receipt Date: October 26, 1973 from Pennsylvania Glass Sand Corporation.

Purity: Used as received.

METHODS

Experimental Animals

Species: One hundred fifty male Charles River, cesarean-derived albino rats.

Weight Range (At Initiation): From 253 to 300 grams.

Housing: Individually in elevated wire mesh cages.

Basal Diet: All animals received a diet of Purina Laboratory Rat Chow and water ad libitum.

Method of Grouping: Stratified randomization by body weight; animals were placed into six groups taking into account the difference in body weight so that a homogeneous distribution of weights was obtained between groups.

Group and Dosage Levels

Group No.	No. of Animals	Dosage Level
1*	25	0
2**	25	10 mg graphite
3ø	25	10 mg quartz
4	25	0.1 mg
5	25	1.0 mg
6	25	10.0 mg

*Group No. 1 served as a vehicle control and received the vehicle only (physiologic saline) at a volume equal to all other groups.

**Group No. 2 served as a negative control and received graphite at a dosage level equal to the high level test animals.

øGroup No. 3 served as a positive control and received quartz at a dosage level equal to the high level test animals.

Compound Preparation

The test material was prepared as a suspension in sterile physiologic saline in concentrations of 0.1 mg/0.5 ml, 1.0 mg/0.5 ml, and 10.0 mg/0.5 ml and administered to Groups No. 4, No. 5, and No. 6, respectively. The negative control (graphite) and the positive control (quartz) were prepared at a concentration of 10.0 mg/0.5 ml and were administered to Groups No. 2 and No. 3, respectively. Group No. 1 served as a vehicle control and received the vehicle only (physiologic saline) at a volume equal to all other groups.

Administration of Test Material

The suspensions were administered by intratracheal instillation at the specified concentrations in a single dose. Dosage volume was equal in all control and test animals.

Observations and Records

Animals were observed daily for mortality, appearance, behavior, and signs of toxic or pharmacologic effects.

Individual body weights were recorded initially, at weekly intervals thereafter, and prior to sacrificing or upon death.

Necropsies

Necropsies were performed and gross necropsy observations were recorded on the single animal which died and on each animal sacrificed. Animals were sacrificed by exsanguination under sodium pentobarbital anesthesia.

Interim Sacrifice: Five male animals randomly chosen from each group were sacrificed at the following intervals; 24 hours, one week, four weeks, and 13 weeks.

Terminal Sacrifice: After six months all surviving animals of all groups were sacrificed.

Tissues Preserved From Each Rat: Lungs, tracheobronchial lymph nodes, spleen, kidney, liver, and any unusual lesions or tissue masses.

Fixative: 10% neutral buffered formalin.

Organ Weight For Each Sacrificed Rat: Lungs.

Tissues Examined Microscopically: All preserved tissues from all groups.

Statistical Evaluation

Criteria: Growth analysis, survival analysis, terminal body weights, lung weights, and lung/body weight ratios.

Methods: Analysis of variance, or F-test (5% probability level) and preliminary tests (where applicable) by methods of Rao, Bartlett, Scheffe, and Fisher-Behrens (modified t-test).

References: Ostle, B., Statistics in Research, Iowa State College Press, Ames, Iowa, 1956; Rao, C.R., Biometrics 14, 1, 1958; Snedecor, G.W., Statistical Methods, Iowa State College Press, Ames, Iowa, 1956; Wilfred J. Dixon and Frank J. Massey Jr., Introduction to Statistical Analysis, 123-124, McGraw Hill, 1957.

RESULTS

Appearance and Behavior

Throughout the six month period of observation there were no biologically significant signs of compound-induced systemic toxicity observed among the animals treated with calcium sulphate anhydrite whisker fibers at any of the three dosage levels. Gross physical observations for these animals consisted of commonly observed incidental signs such as hunched appearance, sores particularly on the tail and other parts of the body, localized alopecia on extremities and body, stains on the fur coat, urine stains on the abdominal fur, and soft feces. These signs occurred at a comparable incidence, at a given point in time, among test groups and the vehicle and negative control groups. Therefore, all test groups are considered to have displayed a pattern of appearance and behavior comparable to the vehicle and negative control groups.

Positive control animals generally displayed patterns of appearance and behavior comparable to other control groups throughout Week 20. However, during the latter stages of the study the incidence of grossly observable signs among this group slightly exceeded that for other control groups including signs associated with respiratory function, such as wheezing and labored respiration.

During the course of the study a single vehicle control animal (No. 16139) was found dead. Death occurred during Week 22 with no grossly observable premorbid signs and was not considered to be a result of the treatment program.

Figure No. 1 - Terminal Survival Data

Group No.	Percent Survival and Standard Error	Mean Time to Occurence of Death in Days
1(vehicle)	80.0 ± 17.9	176.4
2 (negative)	100.0 ± 0.0	-
3 (positive)	100.0 ± 0.0	-
4	100.0 ± 0.0	-
5	100.0 ± 0.0	-
6	100.0 ± 0.0	-

Growth

Group mean body weights, standard deviations, and survival data are presented in appended Table No. 1.

Group mean body weights for selected intervals are also shown in the figure below.

Figure No. 2 - Group Mean Body Weights at Selected Intervals

Interval weeks	Group No. 1	2	3	4	5	6
1	330	330	330	331	335	327
3	381	380	379	380	384	375
5	429	419	425	425	424	400
8	475	467	463	469	474	453
16	549	531	509	542	538	465
26	613	584	551	592	583	524

Statistical analysis of the growth rate, based on the above intervals, by the Chi-square method and the modified t-test (5% probability level) revealed a statistically significant body weight supression in the high level test group when compared to the vehicle and negative control groups. The biological significance of this finding is impossible to ascertain due to a number of factors.

First, food consumption was not monitored and therefore the efficiency of food utilization (weight gained/food consumed) could not be determined and used as a criterion in evaluation of growth rate.

Secondly, evaluation of initial body weight data for all animal groups revealed a somewhat wide body weight range for Group No. 6 animals at initiation. Initial group mean body weights and standard deviations are listed below.

Figure No. 3 - Initial Group Mean Body Weights and Standard Deviations

Group	Initial Mean Body Weight	Standard Deviation
1	272	7.0
2	272	7.7
3	273	7.8
4	273	8.4
5	274	7.8
6	273	18.6

Distribution of body weights for Group No. 6 animals at initiation was such that at all interim sacrifices those animals sacrificed exceeded in body weight by at least 3% those surviving. This was not a factor in the remaining five groups.

Mean body weights for the remaining test groups remained comparable with, or in some instances, exceeded that of the negative control group throughout the course of the study.

Mean body weights for positive control animals were comparable to the negative control group throughout Week 15. During the final 11 weeks of the study, mean body weights for this group were consistently lower than all other groups (excluding Group No. 6); however, not to a degree of statistical significance at a 5% probability level.

Mean body weights for vehicle control animals throughout Week 9 were comparable to the negative control group; however, during the final 17 weeks mean body weights for this group were slightly higher than those for the negative control group.

Gross Necropsy Findings

Evaluation of gross necropsy data on sacrificed test animals at all intervals did not reveal any consistent alterations in any tissue or organ at any level which could be attributed to the administration of the test material. In general, findings consisted of incidental alterations and occurred at a comparable incidence among the test groups and the vehicle control groups. Gross alterations included red areas in the lobes of the lung, pale or red tinged livers, and kidneys with red outer medullas.

Negative control animals revealed dark gray areas of particulate matter in the lungs (presumably the injected graphite) at intervals of 24 hours, one week, and four weeks but the latter was not apparent grossly at the 13 and 26 week intervals.

Necropsy findings for the positive control animals were generally comparable to other control and test groups at intervals of 24 hours, one week, and four weeks. At 13 weeks small gray nodules were found in the lungs of one animal and two additional animals displayed a thickening of the thymus. These conditions were also noted at Week 26 along with enlargement of the peribronchial lymph nodes.

Organ Weights

Group mean body weights, lung weights, and lung/body weight ratios for intervals of 24 hours, one, four, and 13 weeks, as well as for termination, are presented in appended Table No. 2. Statistical analysis of these data revealed a significantly elevated mean lung weight and lung/body weight ratio at Week 1 for Group No. 6 animals when compared to the vehicle and negative controls. In addition, at termination, Group No. 5 animals showed significantly elevated lung/body weight ratios in comparison to the vehicle and negative control groups. However, these significant changes did not show a trend consistent with a compound-related effect since there were no histomorphological alterations of the lungs comparable to those found in the lungs of the positive control animals.

Microscopic Pathology

24 Hour Sacrifice:

Lung sections from all groups showed a pleocellular inflammatory response around the terminal bronchioles and occasionally extending into the lumen. The inflammatory cells were principally neutrophils with occasional macrophages and plasma cells. The vehicle control (Group No. 1) rats had minimal to slight reactions. One rat had no reaction at all. The responses in all three test groups were similar to each other and were comparable to the reaction in the Group No. 1 rats.

The responses occurring in rats of Groups No. 2 and No. 3 were more severe and appeared to be related to the amount of material (graphite or quartz) present. Considerable amounts of these materials were seen in the bronchiolar epithelium and the surrounding tissues in three rats from each of these two groups. In two of the Group No. 2 rats which had no graphite evident, one rat had no reaction while the other had a very minimal reaction. Two of the Group No. 3 rats had only very small deposits of quartz and only a minimal inflammatory response.

The lung sections also revealed slight peribronchial lymphoid hyperplasia in the lungs of all rats. There were also areas of agonal hemorrhage and artifactual lung collapse in many of the sections.

Liver sections in both control and treated groups contained a few areas of minimal nonsuppurative pericholangitis. There was also a scattered incidence of microgranulomas. Kidney sections in some rats in all groups revealed a minimal interstitial nephritis. One Group No. 6 rat also had calcareous bodies at the corticomedullary junction of the kidneys.

One Week Sacrifice:

Lung sections from one Group No. 1 rat and from several of the rats in each of the other groups revealed a perivascular inflammatory reaction consisting mainly of a neutrophilic response with a few lymphocytes. In addition, there was a focal pneumonitis consisting of accumulations of polymorphonuclear cells, macrophages, lymphocytes, and occasional plasma cells in approximately half the rats in each group except the vehicle control group. The reaction appeared to be most severe in the graphite control group and, in many instances, appeared to have a more granulomatous component consisting of more macrophages, activated septal cells and lymphocytes. However, in both the quartz and graphite groups, the cellular reaction appeared to be completely unrelated to the areas of particulate matter deposition.

The smaller quartz crystals and graphite particles were engulfed by alveolar macrophages and the larger particles were completely surrounded by clumps of macrophages. In the case of the quartz crystals, many of the macrophages had a foamy appearance. A few of the Group No. 1 and treated rats also had focal collections of foamy alveolar macrophages.

The focal pneumonitis did not appear to be related to the particulate matter present and in contrast to the lung sections at 24 hours, was not located around the terminal bronchioles. The reaction observed in the high dose treated group was more marked than that observed in the two lower doses. But was comparable to the reaction in the Group No. 1 rat. The reaction observed may be due to a bacterial infection secondary to the stress produced by the intratracheal instillation of the material.

The lung sections also revealed slight to moderate peribronchial and perivascular lymphoid hyperplasia in many of the rats. There were also areas of agonal hemorrhage and artifactual lung collapse.

Liver sections in both control and treated groups contained a few areas of minimal nonsuppurative pericholangitis and there was a scattered incidence of microgranulomas. One Group No. 3 rat had focal areas of vacuolation in the liver parenchyma and one Group No. 6 rat had a focal hepatitis in the subcapsular area.

Kidney sections in several rats in all groups revealed a minimal interstitial nephritis. One Group No. 2 rat had a minimal pyelitis, one Group No. 5 rat had a focal granulomatous area surrounded by an area of hyalinization and one Group No. 4 rat had a moderate interstitial nephritis and a cystic cortex.

Lymph node sections from occasional rats in Groups No. 2, No. 4, No. 5, and No. 6 revealed lymphoid hyperplasia.

Four Week Sacrifice:

Lung sections from several rats in all six groups revealed a perivascular inflammatory reaction consisting mainly of neutrophiles. In addition, there was a focal pneumonitis consisting of activated septal cells, macrophages, and lymphocytes. Lung sections also revealed focal accumulations of foamy alveolar macrophages and slight peribronchial and perivascular lymphoid hyperplasia in many of the rats. There were also areas of agonal hemorrhage and artifactual lung collapse. The responses in all three test groups (Groups No. 4, No. 5, and No. 6) were similar and were comparable to the reaction in the Group No. 1 rats. The reaction was similar to that observed at one week, but more chronic in nature with more chronic inflammatory cells and fewer polymorphonuclear cells.

In Group No. 2 rats, scattered particles of graphite were surrounded by clumps of macrophages. There was little tissue response and the majority of these macrophages with graphite were free in the alveoli.

Group No. 3 rats had numerous silicotic nodules composed of fibroblasts, macrophages, and mononuclear inflammatory cells situated around the terminal bronchioles. Numerous quartz crystals were evident in these nodules and in the surrounding tissue. In addition, the peribronchial lymphoid tissue and the peribronchial lymph node had minute quartz crystals and small fibroblastic nodules.

Liver sections in both control and treated groups contained a few areas of minimal nonsuppurative pericholangitis and there was a scattered incidence of microgranulomas. One Group No. 1 rat had a focal hepatitis, a Group No. 2 rat had subcapsular hepatitis and a Group No. 4 rat had suppurative pericholangitis.

Kidney sections in a few rats in all groups revealed a minimal interstitial nephritis.

In addition to the fibroblastic nodules and quartz crystals observed in lymph nodes in Group No. 3, lymph node sections from occasional rats in Groups No. 1, No. 3, and No. 5 revealed lymphoid hyperplasia.

13 Week Sacrifice:

Lung sections from two rats of Group No. 1, one rat of Group No. 2, and three rats in each treatment group (No. 4, No. 5, and No. 6) revealed a minimal to moderate perivascular inflammatory reaction consisting mainly of neutrophiles. In addition, a focal pneumonitis consisting of activated septal cells, macrophages, and lymphocytes occurred in occasional rats in both control and treated groups. Lung sections also revealed focal accumulations of foamy alveolar macrophages and minimal to marked peribronchial lymphoid hyperplasia in most of the rats. There were also areas of agonal hemorrhage and artifactual lung collapse. The responses in all three test groups (Groups No. 4, No. 5, and No 6) were similar and were comparable to the reaction in the Group No. 1 rats. The reaction was similar but less severe than that observed at one month.

In Group No. 2 rats, scattered particles of graphite were evident in four of the five rats and these particles were surrounded by macrophages. One rat had a focal area of adenomatous hyperplasia which was unassociated with graphite particles.

Group No. 3 rats had numerous silicotic nodules diffusely scattered throughout the lungs in all but one rat. These nodules were composed of fibroblasts and fibrocytes with occasional strands of mature collagen interspersed as well as occasional macrophages and mononuclear inflammatory cells. Occasional nodules were quite large and in many areas, two or more of the nodules had coalesced to form a larger nodule. In addition, many smaller nodules of similar structure were present in the peribronchial lymphoid tissue and in two animals, numerous nodules had formed in the thymus. In all silicotic nodules, numerous small birefringent crystals were evident under polarized light. In all lungs containing silicotic nodules, there was a diffuse macrophagic response throughout the alveoli. The silicotic nodules were much larger and contained more mature connective tissue than was present at one month.

Liver sections from treated and control animals contained a few areas of minimal nonsuppurative pericholangitis and there was a scattered incidence of microgranulomas. One rat in Group No. 6 had slight bile duct proliferation.

Kidney sections from most of the rats in all groups revealed a minimal interstitial nephritis. In addition, one Group No. 2 and one Group No. 4 rat had hydronephrosis and another Group No. 4 rat had a small cyst in the cortex.

26 Week Sacrifice (Termination):

Lung sections from all rats in each group revealed evidence of chronic respiratory disease. The lesions varied from moderate to marked peribronchial lymphoid hyperplasia to frank suppurative bronchopneumonia with abscessation and consolidation. The lesions in all groups were comparable and more severe than the alterations observed at three months.

Three of the five Group No. 2 rats had graphite particles present within the lung sections. There was no apparent reaction to the graphite.

Four of the five Group No. 3 rats had small silicotic nodules diffusely scattered through the lung particularly in the hyperplastic peribronchial lymphoid tissue. In addition, many smaller nodules were present in all thymus sections and in peribronchial lymph node sections from two rats.

Peribronchial lymph node and thymus sections in all groups revealed lymphoid hyperplasia and lymphadenitis. These changes reflect the chronic inflammatory reaction occurring in the lungs. In addition, there was a high incidence of hemorrhage in these tissue sections. This is believed to be due to the process of exsanguination.

Liver sections from treated and control animals contained a few areas of minimal nonsuppurative pericholangitis and there was a scattered incidence of micrograndulomas.

Kidney sections from most of the rats in all groups revealed a minimal interstitial nephritis. In addition, three rats in Group No. 4 had calcareous bodies at the corticomedullary junction.

Spleen sections from most of the rats in all groups contained hemosiderin pigment consistent with the ageing process.

One control rat (Group No. 1) died on the study and was found to have lymphosarcoma affecting both the liver and the spleen.

In conclusion, histomorphological alterations attributable to the test material (calcium anhydrite whisker fibers) were not apparent at any of the dosage levels at any of the above intervals. The positive control rats (Group No. 3), however, developed silicotic nodules consisting of clumps of macrophages, fibroblasts, occasional strands of collagen, and quartz crystals (first evident at the one month sacrifice). These lesions were present in the lung, thymus, and peribronchial lymph node sections and persisted to the end of the experiment.

Submitted by Henry A. Rutter Jr.
HENRY A. RUTTER, Jr., Ph.D.
Project Coordinator
Toxicology Department

Pathology by Richard W. Voelker DVM PhD
for DEBORAH BANAS, D.V.M.
Pathologist
Pathology Department

Report Preparation: Strother
Supervision: McHugh

njo

NOTE: The research described in this report involved animals maintained in animal care facilities fully accredited by the American Association for Accreditation of Laboratory Animal Care.

865-100 . 1

TABLE NO. 1 - MEAN BODY WEIGHTS, WEIGHT RANGES, FOOD CONSUMPTION, AND SURVIVAL DATA FOR MALE ANIMAL

TIME INTERVAL WEEKS	GROUP 1 BODY MEAN G.	GROUP 1 WEIGHT ST DEV G.	GROUP 1 FOOD G.	GROUP 1 SURV.	GROUP 2 BODY MEAN G.	GROUP 2 WEIGHT ST DEV G.	GROUP 2 FOOD G.	GROUP 2 SURV.	GROUP 3 BODY MEAN G.	GROUP 3 WEIGHT ST DEV G.	GROUP 3 FOOD G.	GROUP 3 SURV.
0	272	7.0	0	25/25	272	7.7	0	25/25	273	7.8	0	25/25
1	330	14.1	0	20/20	330	11.0	0	20/20	330	9.3	0	20/20
2	355	15.5	0	15/15	354	17.0	0	15/15	353	10.1	0	15/15
3	381	17.6	0	15/15	380	18.9	0	15/15	379	13.4	0	15/15
4	412	21.1	0	15/15	413	20.2	0	15/15	409	14.8	0	15/15
5	429	26.9	0	10/10	419	24.3	0	10/10	425	12.7	0	10/10
6	433	28.5	0	10/10	439	16.8	0	10/10	427	35.8	0	10/10
7	460	23.8	0	10/10	455	25.5	0	10/10	452	15.1	0	10/10
8	475	30.1	0	10/10	467	21.7	0	10/10	463	18.1	0	10/10
9	488	29.8	0	10/10	482	25.2	0	10/10	480	21.0	0	10/10
10	504	33.4	0	10/10	490	22.3	0	10/10	485	24.5	0	10/10
11	506	35.2	0	10/10	491	21.0	0	10/10	486	24.9	0	10/10
12	526	36.1	0	10/10	510	17.8	0	10/10	496	20.1	0	10/10
13	527	38.4	0	10/10	515	14.4	0	10/10	503	31.9	0	10/10
14	542	55.6	0	5/ 5	523	11.9	0	5/ 5	523	40.8	0	5/ 5
15	536	54.6	0	5/ 5	518	11.5	0	5/ 5	518	40.0	0	5/ 5
16	549	59.8	0	5/ 5	531	12.5	0	5/ 5	509	67.9	0	5/ 5
17	552	56.9	0	5/ 5	539	10.8	0	5/ 5	520	48.7	0	5/ 5
18	564	58.8	0	5/ 5	542	12.8	0	5/ 5	532	45.6	0	5/ 5
19	566	59.6	0	5/ 5	548	14.3	0	5/ 5	536	40.6	0	5/ 5
20	577	63.2	0	5/ 5	558	16.0	0	5/ 5	539	42.6	0	5/ 5
21	579	62.2	0	5/ 5	556	19.4	0	5/ 5	537	47.1	0	5/ 5
22	594	73.0	0	4/ 5	564	23.7	0	5/ 5	539	54.1	0	5/ 5
23	596	75.0	0	4/ 5	568	25.4	0	5/ 5	538	51.4	0	5/ 5
24	600	78.2	0	4/ 5	572	15.1	0	5/ 5	542	43.9	0	5/ 5
25	609	79.9	0	4/ 5	579	15.1	0	5/ 5	546	45.6	0	5/ 5
26	613	79.8	0	4/ 5	584	15.2	0	5/ 5	551	45.7	0	5/ 5

2

TABLE NO. 1 - MEAN BODY WEIGHTS, WEIGHT RANGES, FOOD CONSUMPTION, AND SURVIVAL DATA FOR MALE ANIMALS

	GROUP 4				GROUP 5				GROUP 6			
TIME INTERVAL WEEKS	BODY MEAN G.	WEIGHT ST DEV G.	FOOD G.	SURV.	BODY MEAN G.	WEIGHT ST DEV G.	FOOD G.	SURV.	BODY MEAN G.	WEIGHT ST DEV G.	FOOD G.	SURV.
0	273	8.4	0	25/25	274	7.8	0	25/25	273	18.6	0	25/25
1	331	15.1	0	20/20	335	12.6	0	20/20	327	24.5	0	20/20
2	355	19.5	0	15/15	355	12.1	0	15/15	349	25.4	0	15/15
3	380	29.3	0	15/15	384	13.3	0	15/15	375	26.6	0	15/15
4	409	24.9	0	15/15	413	18.0	0	15/15	400	32.7	0	15/15
5	425	23.3	0	10/10	424	17.9	0	10/10	400	35.0	0	10/10
6	420	47.5	0	10/10	441	24.9	0	10/10	413	37.4	0	10/10
7	457	38.8	0	10/10	455	24.9	0	10/10	433	40.6	0	10/10
8	469	40.3	0	10/10	474	28.4	0	10/10	453	45.7	0	10/10
9	484	43.9	0	10/10	483	30.8	0	10/10	458	47.1	0	10/10
10	493	47.5	0	10/10	491	32.4	0	10/10	462	51.4	0	10/10
11	495	46.3	0	10/10	496	37.0	0	10/10	463	54.9	0	10/10
12	512	49.7	0	10/10	508	38.0	0	10/10	471	53.9	0	10/10
13	517	50.0	0	10/10	520	43.1	0	10/10	481	57.0	0	10/10
14	537	64.3	0	5/ 5	529	42.6	0	5/ 5	471	53.8	0	5/ 5
15	534	62.7	0	5/ 5	525	43.8	0	5/ 5	468	53.5	0	5/ 5
16	542	59.7	0	5/ 5	538	46.2	0	5/ 5	465	41.4	0	5/ 5
17	545	61.3	0	5/ 5	539	41.2	0	5/ 5	468	46.7	0	5/ 5
18	551	67.5	0	5/ 5	543	43.3	0	5/ 5	479	50.1	0	5/ 5
19	568	67.3	0	5/ 5	554	51.3	0	5/ 5	487	52.1	0	5/ 5
20	560	67.6	0	5/ 5	557	51.3	0	5/ 5	500	51.6	0	5/ 5
21	566	63.7	0	5/ 5	558	58.0	0	5/ 5	500	48.6	0	5/ 5
22	578	67.3	0	5/ 5	575	60.3	0	5/ 5	509	40.7	0	5/ 5
23	580	67.0	0	5/ 5	572	56.5	0	5/ 5	511	44.1	0	5/ 5
24	582	68.8	0	5/ 5	573	49.4	0	5/ 5	514	44.3	0	5/ 5
25	585	66.4	0	5/ 5	578	48.7	0	5/ 5	521	48.2	0	5/ 5
26	592	73.2	0	5/ 5	583	49.6	0	5/ 5	524	47.6	0	5/ 5

3
865100

TABLE NO. 2 – MEAN TERMINAL BODY WEIGHTS, ORGAN WEIGHTS, ORGAN/BODY WEIGHT RATIOS, AND STANDARD DEVIATIONS FOR MALE AND FEMALE ALBINO RATS.

24 HOURS

			BODY WEIGHT		LUNGS			
GROUP NUMBER	SEX	N	WEIGHT G.	S G.	WEIGHT G.	S G.	RATIO %	S %
1	M	5	301	6	1.79	0.17	0.595	0.051
2	M	5	294	15	1.53	0.30	0.522	0.094
3	M	5	301	8	1.92	0.39	0.636	0.144
4	M	5	298	10	1.76	0.19	0.591	0.085
5	M	5	297	5	1.65	0.19	0.555	0.060
6	M	5	287	19	1.63	0.35	0.564	0.092

TABLE NO. 2 – MEAN TERMINAL BODY WEIGHTS, ORGAN WEIGHTS, ORGAN/BODY WEIGHT RATIOS, AND STANDARD DEVIATIONS FOR MALE AND FEMALE ALBINO RATS.

ONE WEEK

			BODY WEIGHT		LUNGS			
GROUP NUMBER	SEX	N	WEIGHT G.	S G.	WEIGHT G.	S G.	RATIO %	S %
1	M	5	331	18	1.62	0.26	0.489	0.062
2	M	5	338	7	1.76	0.15	0.521	0.053
3	M	5	328	11	2.00	0.37	0.612	0.113
4	M	5	326	12	1.88	0.26	0.580	0.097
5	M	5	340	13	1.79	0.47	0.527	0.149
6	M	5	335	30	2.45 S+	0.20	0.736 S+	0.083

S+ = Significantly higher than negative and vehicle controls at $p < 0.05$.

TABLE NO. 2 - MEAN TERMINAL BODY WEIGHTS, ORGAN WEIGHTS, ORGAN/BODY WEIGHT RATIOS, AND STANDARD DEVIATIONS FOR MALE AND FEMALE ALBINO RATS.

FOUR WEEKS

			BODY WEIGHT		LUNGS			
GROUP NUMBER	SEX	N	WEIGHT G.	S G.	WEIGHT G.	S G.	RATIO %	S %
1	M	5	402	17	2.33	0.39	0.579	0.078
2	M	5	415	30	2.44	0.53	0.592	0.150
3	M	5	409	21	2.72	0.55	0.667	0.131
4	M	5	407	16	1.75	0.26	0.429	0.060
5	M	5	416	20	1.96	0.29	0.473	0.077
6	M	5	408	28	1.78	0.31	0.437	0.067

TABLE NO. 2- MEAN TERMINAL BODY WEIGHTS, ORGAN WEIGHTS, ORGAN/BODY WEIGHT RATIOS, AND STANDARD DEVIATIONS FOR MALE AND FEMALE ALBINO RATS.

13 WEEKS

			BODY WEIGHT		LUNGS			
GROUP NUMBER	SEX	N	WEIGHT G.	S G.	WEIGHT G.	S G.	RATIO %	S %
1	M	5	516	17	2.42	0.37	0.47	0.06
2	M	5	518	17	2.63	0.74	0.51	0.14
3	M	5	496	17	3.67	1.50	0.75	0.32
4	M	5	506	31	2.24	0.21	0.45	0.07
5	M	5	518	44	2.50	0.66	0.49	0.16
6	M	5	493	60	2.43	0.52	0.50	0.16

865100

TABLE NO. 2 – MEAN TERMINAL BODY WEIGHTS, ORGAN WEIGHTS, ORGAN/BODY WEIGHT RATIOS, AND STANDARD DEVIATIONS FOR MALE AND FEMALE ALBINO RATS.

26 WEEKS

			BODY WEIGHT		LUNGS			
GROUP NUMBER	SEX	N	WEIGHT G.	S G.	WEIGHT G.	S G.	RATIO %	S %
1	M	4	614	80	2.92	0.36	0.48	0.06
2	M	5	584	15	2.74	0.48	0.47	0.10
3	M	5	552	45	3.93	1.30	0.72	0.28
4	M	5	593	73	3.02	0.87	0.51	0.12
5	M	5	583	50	3.46	0.33	0.60^{S+}	0.06
6	M	5	524	48	3.08	0.68	0.59	0.10

S+ = Significantly higher than negative and vehicle controls at $p < 0.05$.

ATTACHMENT D2

SUMMARY OF INTRATRACHEAL STUDIES
BY
DR. GEORGE W. WRIGHT

The Biology of Franklin Fiber® Filler by George W. Wright, M.D.

ABSTRACT: *There are no data concerning the biological reaction of human tissue to gypsum in fiber form but there are pertinent data derived from animal exposure to such, fibers and also from long term exposure of humans to respirable size particles of gypsum of identical chemical make-up but in granular or non-fiber form. Studies carried out in recent times of both human and animal exposure to various materials in fiber form, as for example asbestos fibers, have clearly demonstrated that several essential factors control the nature of the tissue response in terms of fibrogenisis or malignant transformation or the absence thereof. Stated briefly these factors are: (1) The fibers must be short and thin enough to be respirable and be deposited in the most distal areas of the broncho-pulmonary tree. (2) The effects are cumulative-dose-related in the sense of fibers lodged at the fiber-cell interface over a substantial period of time measured in months to years. (3) The developement of an adverse tissue response is related to rather specific diameters and lengths of the fibers that are retained. (4) The fibers must be durable in the appropriate dimension at the cellular level in order to reach the requisite cumulative-dose. Each of these four factors must exist in concert with the others in order that an adverse reaction might ensue following exposure by the inhalation route. Relevant data regarding the behavior of Gypsum with respect to these factors is available. The chemical structure of fibrous and of granular gypsum are the same. Studies of humans exposed occupationally to granular gypsum of respirable size over the past several decades have failed to reveal any adverse biological reaction and the same is true of animal inhalation studies. Most importantly these studies have shown the granular gypsum is very soluble in living tissue. It is not durable and thus does not lead to the required cumulative-dose over time. In a similar fashion, animal experiments involving the direct introduction of gypsum fibers into the lungs or the peritoneal space of rodents have demonstrated rapid dissolution of the fibers and no evidences of fibrogenesis or mesothelioma tumor development. As is true of granular gypsum the fibrous form has also been shown to be not durable in a biological sense and hence it does not accumulate in living tissue—a not surprising observation in view of their chemcial identity.*

I have been asked for a discussion of extant health-related information that would be pertinent to Franklin Fiber (FF) in the hemi-hydrate and anhydrous forms. Chemically, these fibers are geometrical forms of their granular gypsum counterparts and about the latter there is a substantial amount of health and biological information which has been gleaned over the past years. In addition, there now exists some pertinent biological information obtained by animal experimentation with respect to the effects of gypsum in fiber form. Gypsum in a fine, silky, fibrous form exists in nature as Satin Spar and has been used to some extent commercially. I do not know of any documented studies of humans after such exposure.

Since gypsum in its granular form, especially when calcined, is similar or the same chemically as FF, it is pertinent to review the health and biological effects of commercially used granular gypsum. Parkes[1] points out that gypsum in granular form has been used rather extensively for centuries and continues so to be used today. Other kinds of respirable dust such as free crystaline silica (quartz) and asbestos have been recognized for several decades as having overt adverse health effects under the circumstances of their use at the time. In contrast, under similar circumstances of health scrutiny and awareness existing at that same time, exposure to gypsum dust did not lead to overt adverse health manifestations. When the adverse effects of quartz and asbestos dust were recognized and had become the focus of scientific scrutiny in the earlier years of this century, studies of persons exposed to other kinds of dust, including gypsum were made at the same time.

Studies in the 1930's by Sayers and by Riddel of workers exposed to gypsum dust[2,3] revealed no adverse health effects of long-term exposure. This was confirmed by an autopsy study[4] of workers who had experienced substantial exposure to gypsum dust during their employment. The authors report that "no specific pneumoconiotic syndrome occurred." They reported minimal areas of perivascular fibrosis and raise the question of whether or not these were caused by a non-specific and minimal reaction to gypsum. Lack of complete occupational histories in these cases and the finding of high normal values for quartz in the lung ash of three of the four cases make it impossible to evaluate these minimal and non-specific findings in terms of respirable gypsum dust per se.

Exposure of guinea pigs to a cloud of calcined gypsum dust containing 16,000 particles per cubic centimeter for a period of two years, permitting survivors to live another two years, was carried out by Gardner and his associates. This work was ultimately published by Schepers, et al.[5] No untoward reaction was observed, as evidenced by the following quotation from their published report. "Since in previous experiments the intra-peritoneal injection of even an excessive quantity of calcined gypsum particles did not produce progressive fibrosis, it was anticipated that the inhalation of these particles would have no serious effect upon the lungs. That assumption has been verified by the studies reported in this paper. It has been demonstrated that the small increments of fine calcined gypsum particles inhaled into the lungs largely disappear, apparently as a result of solution in the tissues. Very little evidence of their presence can be discovered. Evidences of reaction in the fixed tissues of the lung are minimal, even after exposures to high concentrations for a period of two years." These inhalation studies confirmed the earlier reported intra-peritoneal injection studies by Hiller and Sayers[5] who observed a fleeting non-fibro-genic reaction to a soluble dust. These inhalation and peritoneal studies emphasize the fact that gypsum particles are soluble in the tissues of experimental animals. That the same is true for particles deposited in the lungs of humans is shown by the fact that in the chemical analyses of lungs from gypsum-exposed workers[4] the level of calcium oxide was within limits of normal even after many years of exposure. If gypsum particles made up of calcium sulphate had been retained, rather than dissolved and the calcium excreted, the level of calcium oxide in the lungs of these gypsum-exposed workers would have been far above that of the lungs of normal persons. That gypsum particles dissolve in human tissues is understandable in the light of its relatively high solubility in saline. The evidence with respect to granular gypsum clearly supports the statement by Parkes[1] in his recent text on Occupational Lung Disorders that "In short, gypsum does not cause a pneumoconiosis." Moreover, there is no evidence to my knowledge that even suggests that exposure to respirable granular gypsum leads to an excess occurrence of lung, pleura or periotoneal cancer. In view of its obvious lack of durability, because of its high solubility in human tissue, such a possibility is extremely unlikely. On the basis of what is known to date, the fact that granular gypsum dust is rated by the American Congress of Government Industrial Hygienists in the category of a nuisance dust would appear to be fully justified.

During the past 20-30 years, it has been convincingly shown that substantial exposure to respirable asbestos fibers will lead to an excess occurrence of pulmonary fibrosis (asbestosis), to pleura effusion, thickening and calcification, and to bronchogenic and mesothelial cancer and perhaps laryngeal cancer as well. Because of this experience, fibers of varieties other than asbestos are now considered suspect until they can be shown to behave otherwise.

In those circumstances where a specific variety of fiber has a long experience of use, studies of populations thus exposed provide data pertinent to the potential biological effects of the specific fibers. Lacking this avenue of approach, resort to experimental animal exposure and to knowledge available from past studies as to the mechanisms underlying the biological effects (or absence thereof) must be used. There is an abundance of pertinent knowledge concerning the latter[7,8,9,10,11,12,13,14,15].

1 It is known that to produce adverse effects in the lung or pleura, fibers must be of a size that will penetrate the air-conducting passage to the distal portions of the bronchial tree. Fibers thinner than 3 and shorter than 200 micrometers can penetrate to those deep lung areas, whereas thicker and longer fibers are intercepted in the nose or are deposited on the surface of proximal air conducting regions where they are rapidly removed by the lung cleansing apparatus.

2 The effects of those fibers known to be biologically active are cumulative dose-related in the sense of an accumulation of fibers at the fiber-tissue interface over a substantial period of time. In the human cases of fibrogenesis this is measured in months and for carcinogenesis, in years.

3 Those investigators who have studied the biological effects of fibers have repeatedly stressed that the fibers must be *durable* in order to generate a fibrogenic or carcinogenic response. By durable it is meant that fibers do not dissolve rapidly or become shorter by cross-section fracture. If they go into solution they disappear and hence will not create an accumulating dose.

4 Extensive animal experimentation has convincingly demonstrated that the ultimate biological effects of fiber-shaped particles are related to the diameter and length of the fibers deposited in or on the tissues.[7,8,10,12,15] In general, carcinogenesis is not associated with fibers thicker than 1.5 or shorter than 5.0 micrometers but becomes increasingly associated with fibers that are thinner and longer than these dimensions. To summarize these controlling features of the adverse biological reaction to fibers: First, they must be of a respirable size; second, they must be durable in the tissue; third, they need to be thinner than 1.5 and longer than 5.0 micrometers; fourth, they must accumulate at the appropriate tissue locations in doses sufficient to induce specific change. No one of these is of primary or singular importance. All are essential.

Since the diameter of FFs place them in the respirable range and from what is likely to occur when they are fractured transversely during handling, one can assume that fibers of respirable diameter and length will be present in the workplace where FFs are used. Moreover, since a substantial portion of the fibers are less than 1.5 micrometers in diameter, one must review what is known about the other factors that will influence tissue reaction to these fibers.

Pott, et al[10] injected a fiber form of gypsum intra-peritoneally into rodents and observed these animals over a period of two years. In contrast to fibers of asbestos which persisted in the tissues and produced fibrosis and an abundance of mesotheliomas, the animals injected with gypsum fibers at similar doses failed to develop any mesothelioma and showed little or no fibrosis and only two intra-abdominal tumors conceivably related to the injection of these quite massive doses. These tumors were not the kind known to occur in excess among humans exposed to asbestos fibers. He noted that at the end of 1 year, only a small or no deposition of dust was seen in the peritoneal cavity. In his earlier report of this same experiment in 1974[13] he notes that the gypsum fibers dissolved on the tissues and inferred that this lack of durability accounted for the failure to induce mesothelioma.

Stanton, et al[7] used gypsum as well as other material implants in the pleura which they speak of as being non-durable in nature. These non-durable implants did not produce a higher rate of mesothelioma than occurred in true non-treated controls. While the gypsum used is not clearly identified as being fibrous, it is spoken of as being in contrast to other "exclusively non-fibrous" substances and one would infer that the gypsum was at least partially fibrous in form.

In 1975[15] in preparation for a study of different materials to be used in exploring the influence of the size of fibers upon specific tissue response,[14] Dr. Kuschner and I injected thin fibers of gypsum anhydrite intra-tracheally into guinea pig lungs. When the lungs were examined as early as two days post-injection, no fibers could be found. Additional simultaneous injection of gypsum plus glass fibers as a tracer showed the glass fibers to be present but no gypsum fibers were seen at the end of 48 hours. Because of the rapid solubility of the gypsum fibers in lung tissue, we deemed them unusable for the purposes of our study and they were not a part of our final published report.

A 26 week intra-tracheal toxicity study in rats with a suspension of calcium sulphate anhydrite whisker fibers (FFs) was carried out in 1974 by Hazelton Laboratories Inc.[15] Three fiber dose levels, the highest being at 10 mg per cc, along with separate groups of positive (quartz crystals) and negative (graphite particles) controls, as well as vehicle (saline) controls, were used. Groups of animals were sacrificed at 24 hrs, one week, four weeks, 13 weeks and the study was terminated at 26 weeks. In their conclusion upon termination of the study at half a year they state "In conclusion, histomorphological alterations attributable to the test material (calcium anhydrite whisker fibers) were not apparent at any of the dosage levels at any of the above intervals. The positive control rats (group #3) however developed silicotic nodules consisting of clumps of macrophages, fibroblasts, occasional strands of collagen and quartz crystals (first evident at the one month sacrifice)." The negative outcome of these studies with gypsum in fiber form fits with that of animals exposed to granular gypsum, strongly suggesting that the fibers dissolved, and thus were not durable and hence not fibrogenic. A subsequent search for gypsum fibers in the histological sections from this study was carried out by Walter C. McCrone Assoc. Inc. in 1986. They examined tissue section from rats injected at the highest concentration of 10 mg per cc and sacrificed at 24 hours post injection. They report as follows: "In summary, no Franklin fiber crystals were found in eight of the slides examined. Two slides in which the crystals were discovered contain only isolated occurrences (only two found per slide) and these appeared to be partially dissolved since the crystal faces are rounded. No concentration of Franklin fibers were found on any of the slides." They also examined ten slides from animals injected with the same concentrations of quartz crystals as positive controls and in these the intrapulmonary deposits of quartz particles were readily identified. The slides were examined using not only the "light" but also the scanning and transmission electron microsopy, techniques that should have revealed fibers had they been present.

From numerous studies looking at long-term effects of particles of respirable size, it is apparent that in order to induce an adverse biological reaction such particles must be durable after they are deposited in or on living tissue. Particles that dissolve in a matter of a few days cannot be considered durable in a biological sense. There is convincing evidence that gypsum particles in their hydrated or anhydrite forms are not durable when deposited in living tissue and because of this have not led to adverse biological reactions. In this regard there does not appear to be any difference between their granular or fibrous forms. This is not surprising since the fibrous form is chemically the same as its granular counterpart and one would expect it to behave in a similar fashion insofar as solubility in living tissue is concerned.

Bibliography

1. Parkes, W. R.—Occupational Lung Disorders, 2nd, Edition, 1982; p. 130.

2. Riddell, A. R.—Clinical investigations into the effects of gypsum dust. Can. Public Health J. 25, 1934, p. 147.

3. Brumfiel, D. M.— Gypsum Industry: Clinical Picture and X-ray findings, Proceedings of Fourth Saranac Lake Laboratory Symposium on Silicosis, 1939; p. 170.

4. Schepers, G. W. H. and Durkan T. M.—Pathological Study of the Effects of Inhaled Gypsum Dust on Human Lungs, Arch. of Industrial Health, 1955, 12: p. 209.

5. Schepers, G. W. H., et al.—The Biological Effects of Calcined Gypsum Dust, Arch. of Industrial Health, 1955, 12: p. 329.

6. Miller, J. W. and Sayers, R. R.—USPHS Reports 49: 80-98, 1934; 50: 1619-1623, 1935 and 51; 1677-1689, 1936.

7. Stanton, M. F. et al; Relation of Particle Dimension to Carcinogenicity in Amphibole Asbestoses and Other Fibrous Minerals. JNCI Vol 67 No. 5, Nov. 1981, p. 965.

8. Pott, F. et al; New results from implantation experiments with mineral fibers; Biological effects of man-made mineral fibers. Proceedings of a WHO/IARC Conference, Copenhagen, Vol. 2, April 1982, p. 286.

9. Bignon, J & Jaurand, M. C. Significance of the chemical composition of fibers for their cancerogenic potency; Colloquium on fibrous dusts, Strasbourg, 1982, VDI Report No. 475, Dusseldorf 1983, p. 225.

10. Pott, F. et al; Results of animal experiments concerning the carcinogenic effects of fibrous dusts and their interpretation with regard to carcinogenesis in humans. Zbl. Bakt. Hyg. I Abt. Orig. B 162, 467-505, 1976.

11. Wright, G. W.; Are there characteristics of fibers that influence their biological effect? Symposium on Electron microscopy of microfibers. Proceedings of the First FDA Office of Science Symposium. Pennsylvania State Univ., 1976, p. 3.

12. Harrington, J. S.; Fiber Carcinogenesis: Epidemiologic Observations and the Stanton Hypothesis, JNCI, Vol. 67 No. 5, Nov. 1981, p. 977.

13. Pott, F., et al; Tumorigenic Effect of fibrous dusts in experimental animals; Environmental Health Perspectives, Vol. 9, 1974, p. 313.

14. Wright, G. W. and Kuschner, M. The Influence of varying lengths of glass and asbestos fibers on tissue response in guinea pigs; Inhaled Particles IV, Pergamon Press, Oxford and New York, 1977, p. 455.

15. Hazelton Laboratories, Inc. 9200 Leesburg Turnpike, Vienna, Va. 22180.

16. Wagner, J. C. et al; Mesothelioma in rats after inoculation with asbestos and other materials. British J. Cancer, 1973, p. 173.

IG-213/12-86
Printed in U.S.A

The author, Dr. George W. Wright graduated from Indiana University School of Medicine in 1932. In 1939, Dr. Wright joined the E.L. Trudeau Foundation in Saranac Lake, N.Y. where he developed a Clinical Physiology Laboratory doing pioneering studies of occupational lung diseases and of pulmonary tuberculosis. He was also associated with the activities at the Saranac Laboratory. His studies during this period were concerned with asbestosis, silicosis, coal workers pneumoconiosis and berylliosis. In 1953, he joined the Staff at St. Lukes Hospital in Cleveland, Ohio where he developed a laboratory for the study of cardio-pulmonary disease in humans and also in animal experimentation. He was also active in teaching in the Dept. of Medicine at Case-Western Reserve University where he held the rank of Professor of Medicine. His activities continued in the fields of occupational and non-occupational lung disease. During this period he served on a number of Federal and State committees in the area of his expertise. In late 1972 he retired from these responsibilities but has continued as an active Consultant in occupational pulmonary disease. During the time between 1939 and the present, his studies, either directly or indirectly, have included the biological effects of fibers as observed not only in human but also in animal experiments and have involved not only naturally occurring fibers but also those of a man-made origin.

Glossary of Terms

Bronchogenic: Originating in any larger air passage of lungs.

Carcinogenesis: A transformation of normal cells into malignant new growth cells.

Fibrogenesis: Development of reactionary changes to the deposition of foreign substances into the lung tissues.

Fibrosis: Formation of fibrous scar tissue.

Laryngeal Cancer: Cancer of larynx (the organ of voice).

Mesothelial Cancer: Cancer of pleura.

Pleura: Outer covering of lungs.

Perivascular: Situated around a blood vessel.

Pneumoconiosis: A condition characterized by permanent deposition of substantial amounts of foreign matter in lungs and its reaction with tissue.

Pneumoconiotic Syndrome: Conditions in which lung tissue reacts to foreign substances resulting in a permanent injury to the tissue.

Pulmonary: Pertaining to lungs.

Industrial Gypsum Division
United States Gypsum Company
101 South Wacker Drive
Chicago, Illinois 60606-4385
A Subsidiary of USG Corporation

ATTACHMENT E

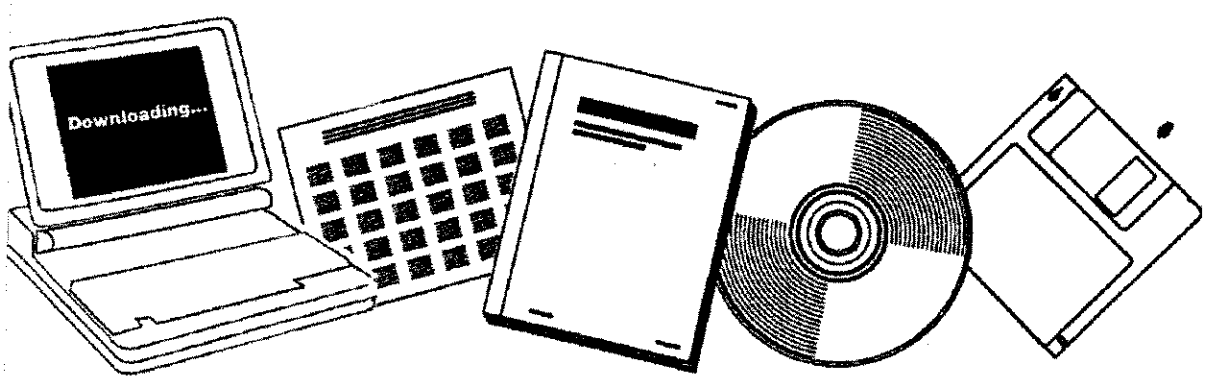
LONG-TERM INTRATRACHEAL STUDY OF FGD GYPSUM

DE88770258

BIOLOGICAL EFFECTS OF A FLUE GAS DESULFURIZATION GYPSUM PRODUCED BY THE LIMESTONE PROCESS

AACHEN TECHNICAL UNIVERSITY (GERMANY, F.R.) MEDICAL FACULTY

26 JUN 1986



U.S. Department of Commerce
National Technical Information Service

Biological Effects of a Flue Gas Desulfurization Gypsum Produced by the Limestone Process

NP--8770258

DE88 770258

Dissertation Approved by the Medical Faculty of
Rhine-Westphalian Technical University Aachen
for Granting of the Academic Degree
of Doctor of Medicine

presented by

Clemens Bartmann
from Marsberg-Essentho
/Westphalian

Examiner: Prof. Dr. med. H. J. Einbrodt

Coexaminer: Prof. MUDr. Jindrich Rosmanith

Date of oral examination: 26 June 1986

Dedicated to the memory

of my parents.

I thank Prof. Dr. H. J. Einbrodt for providing helpful support in carrying out the subject and for work possibilities at the Institute of Hygiene and Occupational Medicine of RWTH Aachen.

I thank Dr. Hollweg and Dr. Lagrange for help in histopathological evaluation of the preparations.

I also thank Dr. Riedel, Ms. Wewer, Mr. Jakobi, who stood by my side in many theoretical and practical problems, as well as all of the Institute employees, who supported me in my work.

Contents

1. Introduction

1.1 Emission and Immission of Sulfur Dioxide (SO_2)

A certain degree of adverse effects on natural conditions is unavoidable in a modern industrial society. It is ultimately part of the price that we have to pay for achieving economic and social progress.

However, we can and must reduce the burdens on our environment to the extent that harmful effects on our environment are largely ruled out. The present generation and future generations are responsible for this and, with available scientific knowledge and technical capabilities, we are also in a position to do this.

Among the gaseous atmospheric pollutants, sulfur dioxide (SO_2) is the most widespread. Investigation of the sulfur cycle in the troposphere led to the finding that about 66% escapes into the air from burning of fossil fuels, about 28% from breakdown of organic matter in the ocean and 3% from that of the soil and another 3% comes from volcanic emissions. Back-transport to earth occurs by washing out with precipitation (65%) and by gas absorption of the water surface (16%) and plants (18%).

Owing to increasing emission of sulfur dioxide (SO_2), especially by burning of fossil fuels, global SO_2 emission has been estimated by calculation since 1860, based on fossil fuel production data (see Appendix, Table 1). Data cited in the literature, however, are sparse and vary sharply. At present, the total anthropogenic SO_2 emission should lie at 90×10^6 t/a (Fig. 1).

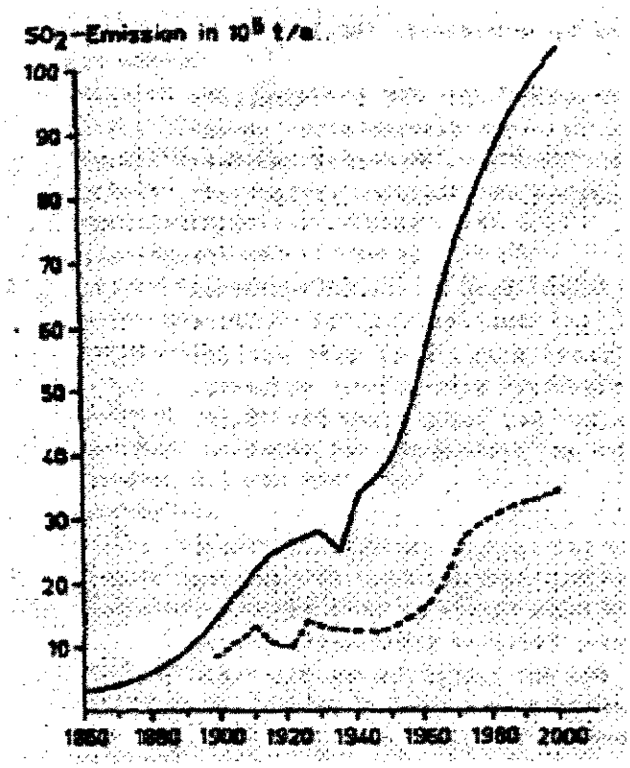


Fig. 1: Development of global anthropogenic SO_2 emission
Dashed line: European SO_2 emission
Source: Möller 1982

The SO_2 emissions in Europe are better known (Fig. 1) and here, especially those of the Federal Republic of Germany, to which reference is subsequently made.

More than 95% of the sulfur dioxide reaches the atmosphere in the combustion process during power production, in which power plants and central heating plants are considered the main emitting groups (Fig. 2 and Appendix, Table 2).

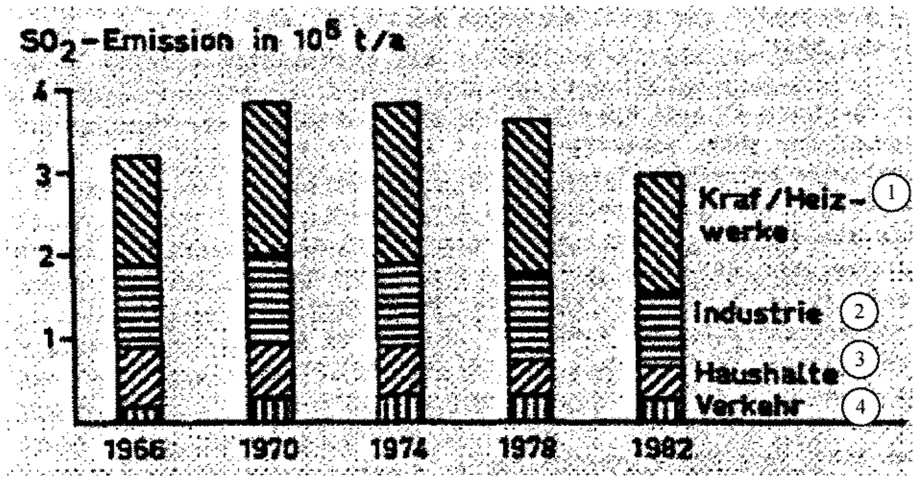


Fig. 2: SO_2 emission in the Federal Republic according to emitter groups
Source: Federal Ministry of the Interior 1984

Key: 1 Power and heating plants
2 Industry
3 Households
4 Traffic

According to the new contract between power engineering and coal mining, the use of domestic coals for power production is to be increased by 1990 to 45 million t/a and by 1995 to 47.5 million t/a coal units (CU) (Pietrzeniuk 1981).

This gives a domestic consumption of coals, including imported coals, of about 85 million t/CU in 1990 (Bund 1979).

Assuming an average sulfur content of the coals at 2% and sulfur release of 95% in the combustion process, a sulfur emission of about 1.7 t/a results from coal alone. The release of sulfur from brown coal and petroleum burning are still not included in this (Einbrodt 1984).

Inhalation of SO_2 produces irritation effects in the mammal body: because of its good water solubility, mostly the upper respiratory tract is affected. Even low concentrations produce spasms of the smooth musculature of the bronchioles, an increase in respiration resistance, as well as an increase in respiration and heart rate. For the plant organism, sulfur dioxide, next to hydrogen fluoride, represents the main pollutant. At a concentration of 0.40 mg/m^3, an acute phytotoxic effect occurs. Values that are still sufficient to protect human health are no longer sufficient for protection of vegetation (Nolte 1973, Tanner et al. 1981, Mileman 1981, Kerr 1981, Sequeira 1982).

These development trends in anthropogenic sulfur emission and the harmful effect on humans and the biosphere resulting from them demonstrate that strategies that permit consideration of ecological aspects must be employed here.

1.2 Legal Provisions and State of the Art

1.2.1 The Federal Immission Control Act (BImSchG) and the Ordinance on Large Combustion Plants (13^{th} Federal Immision Control Ordinance)

Through the constitutional amendment of 12.04.1972, the State acquires competing legislative authority for waste disposal, air pollution control and noise control (Constitution Art. 74 (24)).

Based on this constitutional amendment, the Federal Immission Control Act (BImSchG) was passed on 13.03.1974. This law thoroughly codifies protection and care against damage from air pollution, noise, vibration, light, radiation, etc., in animals, plants and materials.
Installations subject to licensing, in particular, are included, like power plants and central heating plants, as well as traffic. According to §4 of BImSchG, the technical instruction for air pollution control (TA Luft) of 8/28/1974, with consideration of the amendment of 2/23/1983 (GmBl, page 94), stipulates a management procedure for installations subject to licensing, which TA-Luft of 9/8/1964 (GmBl, page 439) exempted from a significant part of the principles of the Federal Immission Control Act in detail. The objectives of this management procedure are immission values that may not be surpassed for the purpose mentioned in § 1 BImSchG, emission values, surpassing of which is avoidable according to the state of the art, as well as methods for determination of emissions and immissions.

According to § 61 BImSchG, the Federal Government regularly prepares a report for the Bundestag [Parliament – lower house] concerning the status and development of emissions, immissions and technology. The so-called GFAVO (13^{th} BImSchV) resulted from this in 1983, which has been in force since July 1, 1983 and specifies the requirements on combustion plants with more than 50 megawatt (MW) thermal power, according to § 5 (2) BImSchG (basic protection law).
In particular, emission values for dust, oxides of nitrogen (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), as well as halogen compounds, from solid, liquid and gaseous fuels in old and new installations were established, (see Appendix, Table 3).

A new feature of this 13^{th} Federal Immision control ordinance is limitation of sulfur dioxide in flue gas from the previous 650 mg/m^3 to 400 mg/m^3, as well as the obligation to retrofit old installations with flue gas desulfurization units by 6/30/1988.

On 2/21/1986, the Bundesrat [Parliament – upper house] decided to amend the "First General Management Procedure for the Federal Immission Control Act" (TA-Luft '86).
Overall, the technical instruction for pollution abatement of air of 8/28/1974, amended on 2/23/1983, is superseded by this. Relative to TA-Luft 1974, this is a clear separation of the emission part from the immission part. The independence of the basic obligation in § 5 (2) BImSchG (Prevention of Harmful Environmental Effects) relative to § 5 (1) (Protection from Harmful Environmental Effects) emerges with it (General Management Procedure of the Federal Government, printing 60/86 1986).

1.2.2 Desulfurization Methods and End Products

History and Development of Flue Gas Desulfurization Units REA [German]

The first installations for desulfurization of power plant waste gases were developed and industrially introduced in the USA and Japan, i.e., in countries with high industrialization.

Especially in Japan, with explosive industrial growth and, at the same time, high population density on an intact environment, a reduction in flue gas emissions had to be introduced, in particular.

The first industrial flue gas desulfurization unit in Japan went into operation as early as 1969. The methods developed in Japan were exclusively wet methods, which used quicklime and strong alkalis as absorption agents and produced usable gypsum as end product. This route was certainly prescribed because Japan has no natural gypsum deposits, but does have a highly developed gypsum industry with high total annual consumption. Since then, all of the natural gypsum imports have been replaced by flue gas gypsum.
In the USA, where much more spacious areas are available than in Japan, other ways for desulfurization were pursued. Methods were developed here with sulfide as residual substance, which was dumped either as sludge or with fly ash as a stabilizer.

The Lime Washing Method

Starting from the experiences obtained in the United States and Japan, flue gas desulfurization methods were further developed and constructed in the Federal Republic of Germany, which used lime in the form of calcium hydroxide ($Ca(OH)_2$) or calcium carbonate ($CaCO_3$) as absorption agent for separation of sulfur dioxide (SO_2).
The principle of this method is based on reaction of sulfur dioxide with calcium to calcium sulfate ($CaSO_4$) (Bloss 1982, Bakke 1980, Gutberlet, Stappert 1981).

On the example of the Knauf-Research-Cottrelle Process (K-R-C Process) in the Federal Republic, the principle of this flue gas desulfurization will be explained (Fig. 3): the chemical reactions in this process occur in two loops. One therefore speaks of a two-loop process.

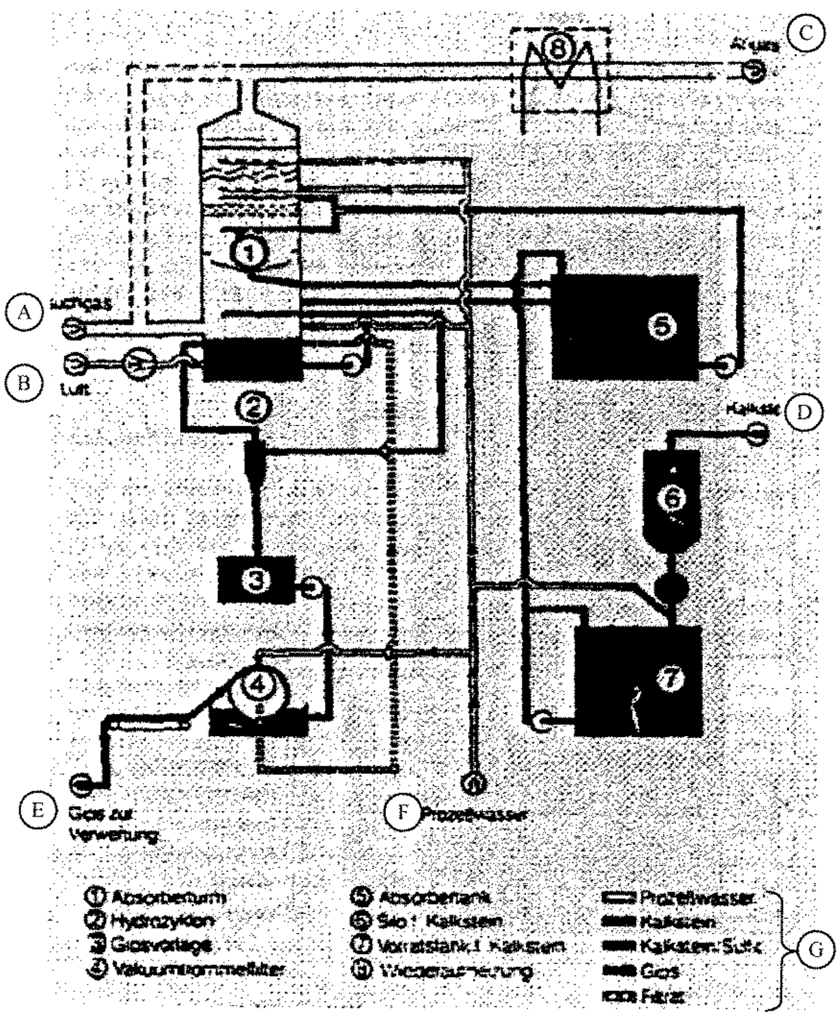


Fig. 3: Flow chart of the K-R-C-Process for flue gas desulfurization

Key:	A	Flue gas
	B	Air
	C	Waste gas
	D	Limestone
	E	Gas for utilization
	F	Process water
	G	Process water
		Limestone
		Limestone/sulfate
		Gypsum
		Filtrate
	1	Absorber tower
	2	Hydrocyclone
	3	Gypsum receiver
	4	Vacuum dryer filter
	5	Absorber tank
	6	Silo for limestone
	7	Supply tank for limestone
	8	Reheating

The key element of the installation is the absorber tower (Fig. 4). The flue gases are initially freed of dust in an electric filter and go to the lower part of the tower tangentially, the so-called quencher. The flue gas is then placed in rotating movement, cooled and saturated with steam. In the quencher, the washing suspension (quencher suspension), consisting of limestone flour and water, of the lower absorber loop is sprayed against the flue gas in two nozzle levels. Part of the sulfur dioxide contained in the flue gas is then already removed.

The entire absorber tower is subdivided into two absorption zones by collector funnels. The flue gas passes along the collector funnel from the lower to the upper absorption zone. The gas stream is then deflected from the rotating direction to a vertical flow direction. The flue gas flows through a spray zone in the upper part of the absorber tower with one nozzle level and then a wet film contact in succession. Here, the wash suspension of the upper absorber loop, the so-called absorber suspension, is sprayed against the flue gas and produces a residual desulfurization.

After flowing through a two-zone drop separator, the purified flue gas escapes the atmosphere from the absorber tower.

Oxidation and gypsum production occur in the lower quenching loop. Large, compact gypsum crystals are formed here, which do not exhibit the disadvantageous thixotropic behavior of smaller gypsum crystals of the upper absorber loop. A hydrocyclone system collects and separates the large, compact gypsum crystals from the small, still not intergrown crystals and conveys them to the quenching loop. This recirculation of the so-called crystallization nuclei is used for further gypsum formation and is continued until large, compact gypsum crystals are formed, can be separated in the hydrocyclone system and then fed to a vacuum drum filter. Here, they are dehydrated to a residual moisture less than 10% and compacted. (Gräfeling 1979, Weiler 1980, Hamm and Hüller 1982, Wirsching 1983).

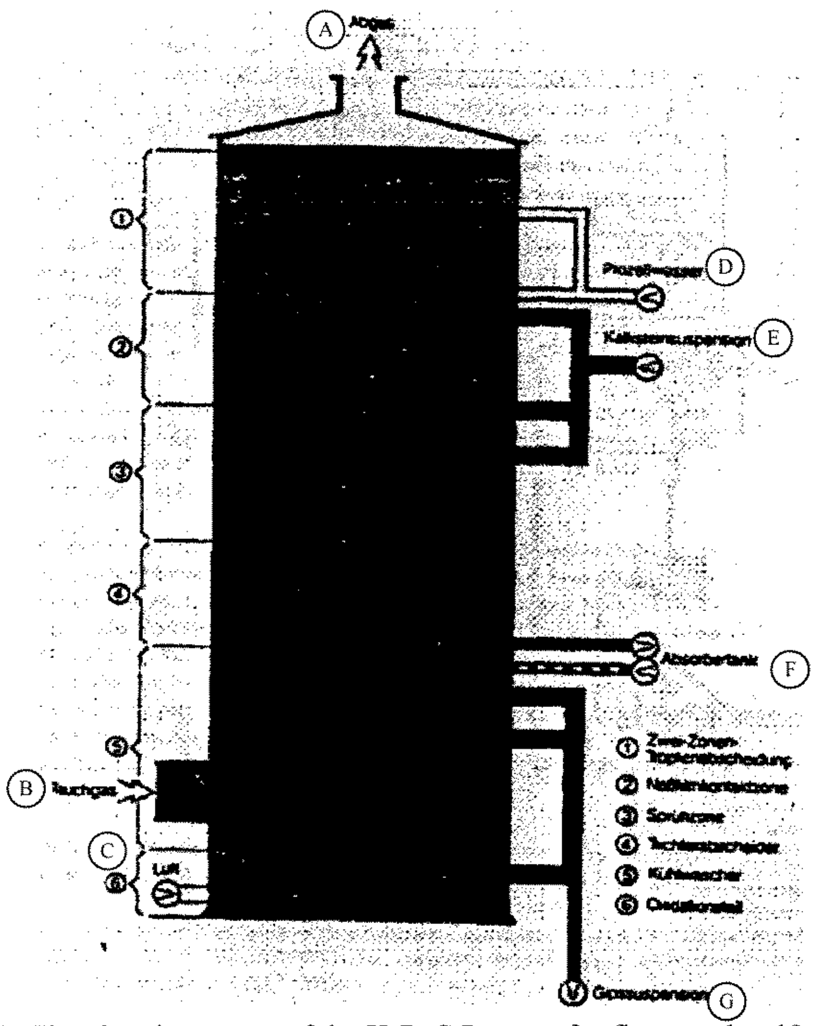


Fig. 4: The absorber tower of the K-R-C Process for flue gas desulfurization

Key: A Waste gas
B Flue gas
C Air

D	Process water
E	Limestone suspension
F	Absorber tank
G	Gypsum suspension
1	Two-zone drop separation
2	Wet film contact zone
3	Spray zone
4	Funnel separator
5	Cooling water
6	Oxidation part

The Ammonium Sulfate Process

The fundamental idea of this process is based on washing with a highly concentrated salt solution.
The flue gas freed of dust is then mixed with ammonia (NH_3) and reacts stoichiometrically to ammonium sulfate (NH_4SO_4). This dust-like end product can be packaged in a pelletizing installation and then supplied to the fertilizer market.

The acceptance of this process is evaluated differently in the literature. This might be justified economically with the uncertain market position for fertilizer, but also might have ecological reasons, since ammonium sulfate has only limited use, because of its properties that acidify soil (Gräfeling 1978, Fertilizers from Gas 1978, Gerking 1979, Fertilizers from Power Plant Waste Gases 1982).

1.3 Disposal of End Products

One of the most important requirements in selecting a desulfurization process is reliable and long-term disposal of the desulfurization products.

According to § 5, No. 3 BImSchG, the legislature requires that installations for flue gas desulfurization be built and operated so that the residues are properly and harmlessly utilized or, if this is not technically feasible, eliminated properly as wastes.

Conversion of sulfur dioxide to gypsum and its utilization in a recycling process has been shown to be the most promising technically and economically. The Federal Republic of Germany consumed about 6 million tonnes of natural gypsum in 1980, 1.5 million tonnes of which were in the cement industry, 3.5 million tonnes in the gypsum industry for production of gypsum construction materials, 0.2 million tonne for production of industrial gypsum and 0.8 million tonne as mine support material in coal mining (Wirsching 1983).

This consumption declined in 1982. With the overall economic position and the expected construction activities in the future, further expansion in the mentioned field is not expected. This situation in the gypsum market in the Federal Republic of Germany is in contrast to the amounts of flue gas gypsum that will be produced in the future during power plant desulfurization.

Considering the amounts of gypsum now produced from flue gas desulfurization of brown coal and bituminous coal of about 4.5 million t/a, with an increase of 30% in 1990 by increased use of bituminous coal, the entire amount of natural gypsum would be replaced from the market. The unused excess would then have to be dumped, as is already practiced in brown coal desulfurization (Einbrodt 1984). The problem of landfill capability should not be overlooked here. Instead, we must examine, from the standpoint of preventive medicine, the extent to which heavy metals contained in flue gas gypsum can cause health impairment in persons occupationally exposed to this material, as in commercial reprocessing in the construction industry or in filling so-called voids in mining operations.

1.4 Statement of the Problem

After the industry considered the technical problem of flue gas desulfurization to have been solved (Lukas 1981), the aspects of possible ecological effects of the end products have not attracted much attention since. The question is therefore raised whether the problem of SO_2 emission has ultimately been solved by the process engineering solution of flue gas desulfurization, or whether this merely represents a rearrangement or even a displacement of our present environmental problems.

Adverse effects on organisms by organic or inorganic products can manifest themselves in a variety of ways. Harmful changes, coupled with far-reaching consequences, manifest themselves as a change in the genome and then possibly the development of malignant tumors. Consequently, for the safety of the substance, one starts from the present state of scientific knowledge to largely rule out mutagenicity and carcinogenicity.

2. Material and Methods

2.1 Characteristics of the Dust

The dust being investigated is a dust-like industrial gypsum, which was recovered according to the desulfurization method outlined in the introduction, using the lime washing principle.

The dust appears under a microscope as a crystalline structure of uniform optical density and a particle size between 30-65 μm (Figs. 5, 6).

Fig. 5: REA gypsum dust. Magnification 225×, phase contrast

Fig. 6: REA gypsum dust. Magnification 900×, phase contrast

2.2 Ames Mutagenicity Test

General

Mutagenic and carcinogenic substances can trigger different changes, gene mutations and chromosome damage, as well as cytogenic effects. Gene mutations can be detected in vitro in bacterial and mammalian cells. However, since not all mutagenic and carcinogenic substances trigger gene mutations, some can also induce other effects and, in principle, in vivo test methods are unavoidable for evaluation of the substance. This is true all the more so, because in vitro methods need not always be representative for the animal organism. Performance, however, is not always practicable. Consequently, it is initially necessary to select a test that is simple to conduct, easy to standardize and has relatively good information content.

These requirements are largely met in the Ames mutagenicity test. It is based on the fact that appropriate *Salmonella typhimurium* mutants that are readily suitable for recording gene mutations are incubated together with the so-called S-9 fraction of a rat liver homogenate. The S-9 fraction is necessary for metabolic activation, since most mutagenic or carcinogenic substances themselves are not toxic (Mattern and Greim 1978). Instead, reaction products that are ultimately responsible for genetic effects are formed only by metabolization of the substances. The rat liver homogenate is recovered from animals that were treated beforehand with a mixture of polychlorinated biphenols (PCBs). Polychlorinated biphenols are considered the strongest inductors of mixed functional oxygenases (Forth 1978).

The system therefore combines the metabolic capacity required for metabolization of chemicals with a sensitive detection of the genetic effect of the forming reacting metabolites. Since the test records gene mutations and bacteria and therefore represents a demonstration of mutagenic effects, it is of special interest to determine the extent to which carcinogenic substances are also recognized with the test.

Ames et al. (1973), who developed the test, were able to demonstrate in 300 carcinogenic substances that 90% of these carcinogens also had a mutagenic effect. Several research groups have more or less confirmed this finding (Purchase 1976, Ashby and Styles 1978). In other studies from the National Cancer Institute of the USA, on the other hand, a lower correlation is mentioned (Poirier, de Serres 1979, Rosenkranz et al., 1979). Both benzene and diethylstilbestrol, which are known to be carcinogens in human, were negative in the mutagenicity test (Ames 1975). Tiedemann and Einbrodt, in 1982, were unable to detect

mutagenicity in the Ames test for arsenic, which is also listed among the inductors of malignant tumors.
Such false-negative findings can partly be explained by the fact that enzymes that would be necessary for activation of the test substance are not present in the test system. Substances are metabolically inactivated, spontaneous back mutations can occur, or the free mutagenic metabolites are so limited, because of unduly high protein contents, that no increased mutation rate is detectable (Mattern and Greim 1978).
In considering these possibilities for error, however, the test has established itself as a screening method.

Performance
The investigation occurred as stated by Ames (1975). Histidine-deficient mutants of *Salmonella typhimurium* TA 1535, TA 1537, TA 1538, TA 98 and TA 100 were used as test germs.

25 g of REA gypsum was shaken out in 300 mL dichloromethane (CH_2Cl_2), concentrated to dryness on a rotary evaporator and taken up in 5 mL dimethyl sulfoxide. A five-stage dilution series (1:5) was prepared from this solution. Each dilution stage was incubated with the test germs in a threefold charge, specifically with and without liver enzyme addition. The spontaneous mutation rate with and without S-9 fraction was also determined for each strain.

The revertants are determined in an automatic colony counter. The average is formed from the three parallel samples and the average spontaneous mutation rate derived from it.

2.3 Animal Experiment

Since, as already mentioned above, in vitro tests on the mammal organism are not absolutely transferable, it is appropriate to use a method that is adequate to the environmental conditions and permits more accurate evaluation of this substance with respect to cytopathogenic effects.

As early as 1955, Schlipkötter advanced the view that, in principle, any inhaled dust is capable of triggering a change somewhere in the respiratory tract.

Under these conditions, it was to be clarified in an animal experiment how the mammal organism deals with a dust load, created under standard conditions, with REA gypsum and whether the reaction represents a specific reaction to this dust.

The experiments were conducted on 85 young, healthy female rats of the Wistar type F 90. The weight of the animals at the beginning of the experiment was 220 g, that of the just sacrificed animals averaged 345 g.

Dust Application

The industrially produced gypsum was administered intratracheally to the animals under slight ether narcosis under nonsterile conditions, specifically in the form of a suspension of 25 mg dust per 0.5 mL physiological saline (0.9% NaCl). In order to keep the gypsum dust optimally in suspension, this suspension was agitated for 15 min with a magnetic stirrer before administration. Administration occurred with a 2 mL syringe with long atraumatic button cannulas.

Overall, 48 animals were treated as described. 37 animals served as control.
The animals were sacrificed by excess ether narcosis and exsanguination after 24 h and after 1, 3, 8 and 18 months.

Histology

Histological preparations of the right upper lobe of the lung and the mediastinal lymph nodes were prepared from all animals. The preparations were stained in hematoxylin-eosin (HE) and resorcinol-fuchsin (Elastica van Gieson) and evaluated under a light microscope.

2.4 Analytical Determinations

The remaining lung, as well as liver, right kidney and right femur, from the animal experiment were fixed in acetone and preserved in a vacuum drying cabinet at 50°C for chemical investigation. The upper part of the left lung was separated from the 18-month fraction for hydroxyproline determination.

2.4.1 Flameless Atomic Absorption Spectrometry

To detect quantitative dust retention in the animal experiment, chemical detection of elements, like chromium, nickel and aluminum, is used. These elements are quantitatively contained in the largest amounts in the administered dust. A carcinogenic or fibrogenic effect of these elements is also assumed.

For this purpose, flameless atomic absorption spectrometery in a Beckmann Atomic Absorption Spectrometer Model 1272 was used. This is the method of choice, in order to detect the smallest amounts of substance in biological samples, since it permits accelerated analyses, without long workup procedures, with high sensitivity.

Measurement Principle and Measurement Arrangement

The method was described for the first time in 1974 by Fuchs et al., in serum aluminum determination and has since found a broad application spectrum, because of further equipment development and improvement.

The sample, after drying and thermal destruction of the matrix, is instantly atomized in an electrically heatable graphite tube: the biological components incinerate and the elements are atomized out from their molecular bonds.

From the light beam of a hollow cathode lamp, peripheral electrons of the atoms being investigated now absorb specific light quanta to jump to a higher energy outer orbit (resonance absorption). During their reflection to the initial level, the same light quantum of defined wavelength is liberated in all directions, so that light attenuation (extinction) occurs in a spectral line specific to the element, which is proportional, according to the Lambert-Beer Law, to the number of atoms present. A monoelement, hollow cathode lamp serves as light source. The measurement beam is broken down spectrally by means of a grating after passing through the atomization cell, in order to separate a specific wavelength. This is then released through a gap of 0.7 nm.

A photomultiplier quantifies even the weakest changes in this light signal, and the extinctions are recorded similarly by a plotter.

The cylindrical graphite tube, which is equipped on the inside with a pyrolytically coated plate, the so-called Love platform, and guarantees better heating, is secured on both ends by a water-cooled, electrically-conducting sleeve. The cylinder itself is rinsed on the inside and outside by an inert protective gas, in order to prevent burn-up of the tube and oxidation of the sample (Schmidt 1978, Weiz 1973).

After introducing the sample volume from the top through the metering opening, the cell is heated electrically by a DC voltage of about 12 V with high current flow (about 500 A) according to a defined temperature-time program. The individual analysis steps for this program are set up specifically for each element and are schematically shown in Table 4 (see Appendix).

During drying, the aqueous components evaporate and, with increasing temperatures, the organic substances are incinerated. During instantaneous heating, atomization occurs; the released atoms spend about 1 sec in the measurement light beam, during which the maximum absorption is measured and recorded. During the atomization phase, the gas flow is briefly interrupted (gas stop), in order to keep the analysis atom optically in the measurement beam.

Performance

The organs being investigated (femur, kidneys, liver and remaining lung) were weighed in a platinum crucible and incinerated in the so-called muffle furnace at 400°C or 720°C for 20 h.

The weighed sample, after incineration, was mixed with 3 mL 6N HCl, evaporated via a steam bath and dissolved in 10 mL 2N HCl after cooling. This analysis product so prepared served as a sample for the elements being determined in the individual organs.

Quantitative evaluation occurred by extinction comparison of standardized calibration solutions in dilution series. The calibration curve gave a linear relationship.

2.4.2 Hydroxyproline Determination

The collagen fibers and connective tissue differ from other proteins in their amino acid sequence. A high percentage of proline and hydroxyproline, as well as a low content of tyrosine and an absence of tryptophan, are characteristic in the repeating tripeptides (Löffler 1979).

During inflammatory processes, in which inflammation cells release abundant collagenases, collagen is broken down to hydroxyproline-containing peptides and free hydroxyproline. This is not reutilized and can therefore be used as an indicator of collagen conversion. Stegemann, in 1958, described a method for detection of hydroxyproline in collagen-containing tissue, which is not prone to disturbance relative to low-hydroxyproline and tyrosine-rich tissue.

The analysis is based on conversion of hydroxproline to pyrrole by chloramine-T and reaction of pyrrole with p-dimethylaminobenzaldehyde to a red dye. The dye intensity is proportional to the hydroxyproline content and is determined by extinction in the flame photometer. Evaluation occurs with standardized calibration solutions in dilution series.

Performance

The fresh lung tissue was initially defatted three times at three-day intervals in acetone, then hydrolyzed in 10 mL 6N HCl at 104°C for 18 h. The hydrolyzate is filtered through cotton wadding and neutralized as 10 mL 6N NaOH. The analysis procedure of this hydrolyzate so recovered from the top of the left lung was done according to Stegemann (1958).

3. Results

3.1. Mutagenicity in the Ames Test

A substance is considered mutagenic if at least one test strain reveals double the spontaneous mutation rate and a clear dose-effect relation.

An increased number of revertants either with or without liver enzyme activation could not be detected in this test in any of the employed test strains of *Salmonella typhimurium*. This REA gypsum is therefore not classified as mutagenic according to Ames (1975). The result of the mutagenicity test is shown graphically in the histogram (Fig.7).

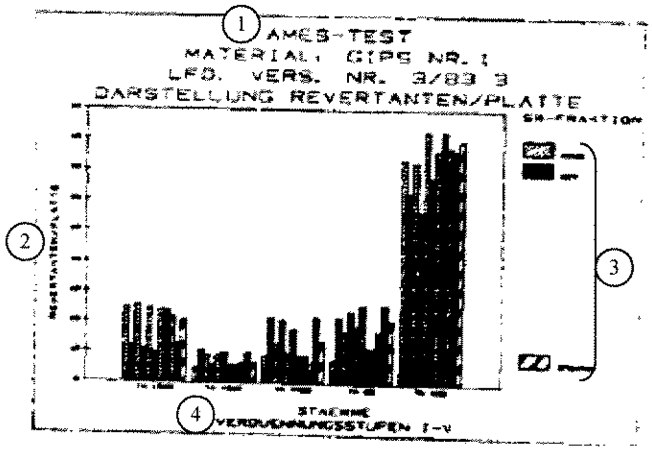


Fig. 7: Revertants in Ames test.

Key: 1 AMES TEST
MATERIAL, GYPSUM NO. 1
VERSION NO. 3/83 3
PREPARATION REVERTANTS/PLATE
2 SR FRACTION
3 [illegible]
4 REVERTENTS/PLATE
STRAINS
DILUTION STEPS I-V

3.2 Pathological-histological Results

24-hour Results

In the histologic preparations of the lung, the administered dust is already no longer detectable under a light microscope after a day. Moderate alveolar septal widening with lymphocyte infiltration is found (Fig. 8).

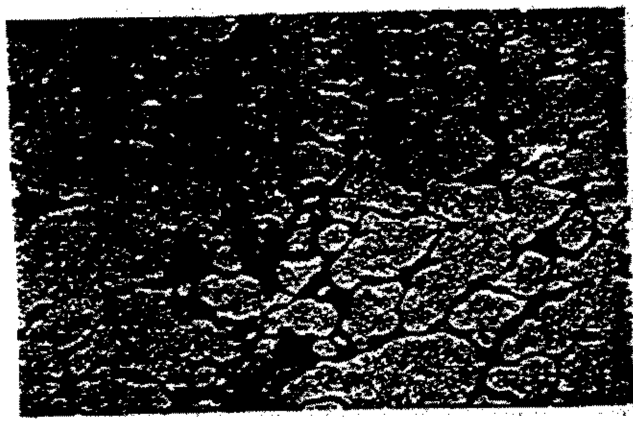


Fig. 8: Alveolar septa 24 h after dust administration, HE 225×

A pronounced pathological delimitation relative to the control animals is not possible, since similar reactions are observed here (Fig. 9).

Fig. 9: Alveolar septa of control animals. 24-hour investigation, HE 225×

The lymph nodes of both the experimental animals and the control animals permit good differentiation in the medulla and cortex. The secondary follicle, with its reaction centers principally situated in the cortex of the lymph nodes, suggests good lymphatic reactivity (Figs. 10 and 11).

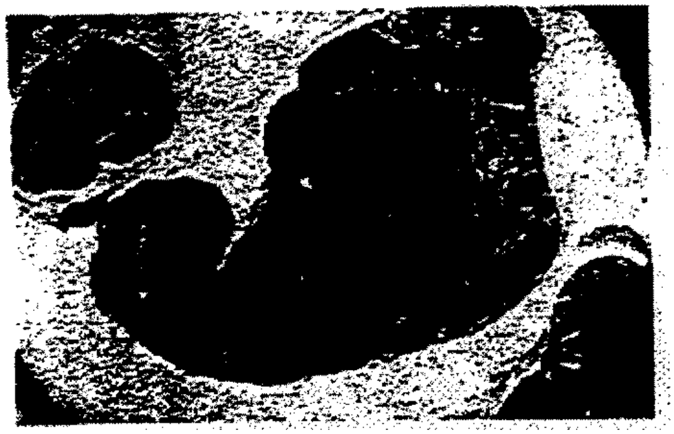


Fig. 10: Lymph nodes 24 h after dust administration, HE 70 ×

Fig. 11: Lymph nodes of control animals after 24 h of experiment time, HE 70 ×

1-Month Result

After 30 days of experiment, the lung preparations of the experimental animals show mucus-filled bronchi with strong longitudinal creasing of the multi-row ciliated epithelium. The vessels are filled with blood and the pronounced alveolar septal widening extends to larger areas of the lung (Fig. 12).

Fig. 12: Lung tissue 30 days after dust administration, HE 280×

Especially in areas with perivascular edema, which compresses the adjacent pulmonary parenchyma, a strongly developed lymphatic tissue is found (Figs. 13, 14). Reliable pathological delimitation relative to the control preparations is not possible here either. Collagen multiplication in the sense of connective tissue proliferation is also not detectable in EVG staining (Fig. 15).

Fig. 13: Perivascular edema with adjacent parenchyma compression, HE 225×

Fig. 14: Perivascular lymphatic tissue, HE 225×

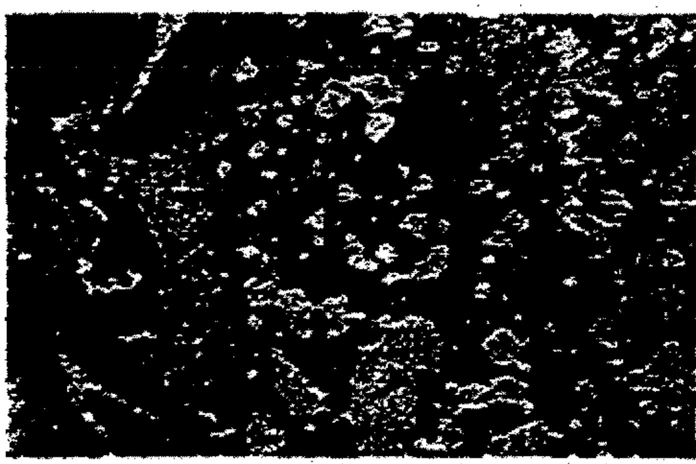


Fig. 15: Perivascular edema, EVG 280×

The lymph nodes showed distinct blood accumulation in all lymph nodes with hemosiderin-laden histiocytes (Figs. 16, 17), chiefly in the intermediate sinus.

Fig. 16: Lymph nodes with hemosiderin-laden histiocytes,
EVG 225 ×

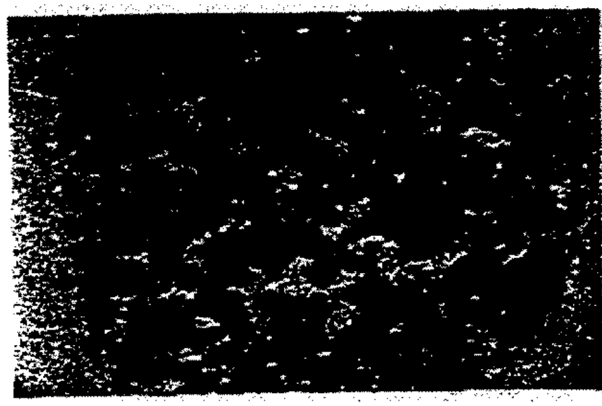


Fig. 17: Blood and hemosiderin accumulation in lymph nodes.
Interference contrast: 900×

3-Month Results

After 90 days of experiment, disseminated, sometimes confluent foci with alveolar septal widening is seen, which are infiltrated with round cells in the lungs of the animals treated with dust (Figs. 18, 19). Edematous swelling compresses the adjacent pulmonary parenchyma. Fibrosis tendencies are not detectable in sometimes-atelectatic lung tissue (Fig. 20). The peribronchial connective tissue is easily delimited relative to its surroundings.

The control animals also show blood-filled vessels, but not such distinct septal widening of the alveoli (Fig. 21). The lymph nodes of the experimental animals, as well as those of the control population, show no conspicuous features (Fig. 22).

Fig. 18: Disseminated focus of alveolar septal widening with round cell infiltrates, HE 180×

Fig. 19: Confluent focus of widened alveolar septa, HE 180×

Fig. 20: Peribronchial connective tissue and perivascular edema, EVG 180×

Fig. 21: Lung tissue of control animals after 3 months of experiment, HE 225×

Fig. 22: Inconspicuous lymph nodes of control animals after 3 months, HE 280×

8-Month Results

In the preparations after 8 months of experiment, large-area zones of former pulmonary parenchyma infiltrated with immune-competent cells are found. Former alveoli are filled with macrophages, foam cells and polymorphonuclear leukocytes in Fig. 23.

In the EVG staining, these structures of collagen connective tissue are apparent (Fig. 24). In the areas of massive septal widening, macrophages and foam cells with foreign body accumulation are apparent (Fig. 25). These foreign bodies appear in polarizable light as bright spots (Fig. 26), in which they might be the finest parts of the administered gypsum dust. A connective tissue reaction was not detectable in these areas (Fig. 27).

Fig. 23: Polymorphonuclear leukocytes and foam cells in former pulmonary parenchyma, HE 720×

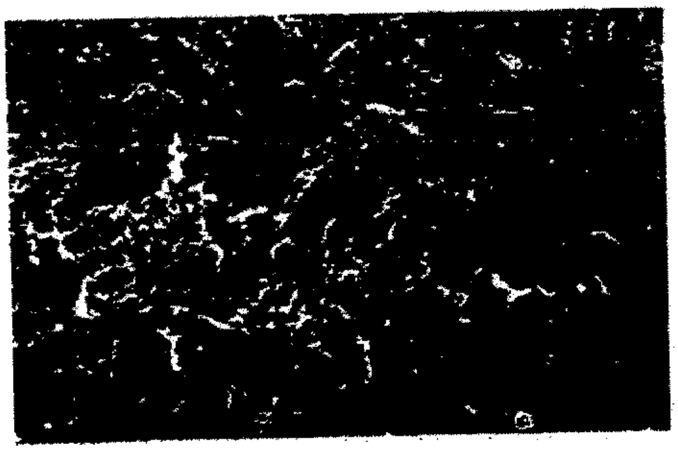


Fig. 24: Fibrosis tendencies after 8 months of experiment, EVG 720×

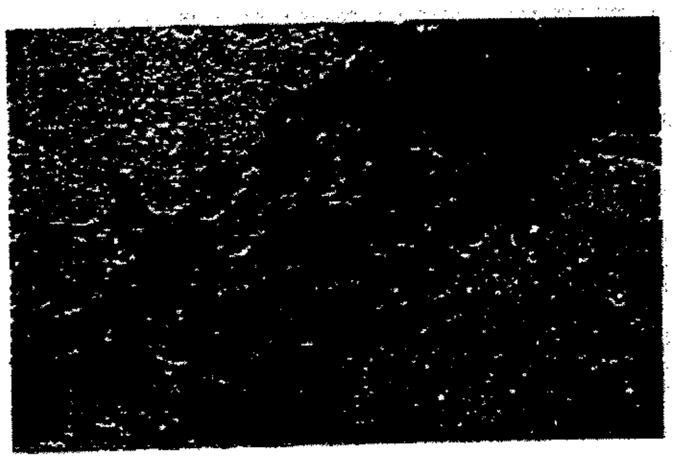


Fig. 25: Foam cells with foreign body accumulation, HE 900×

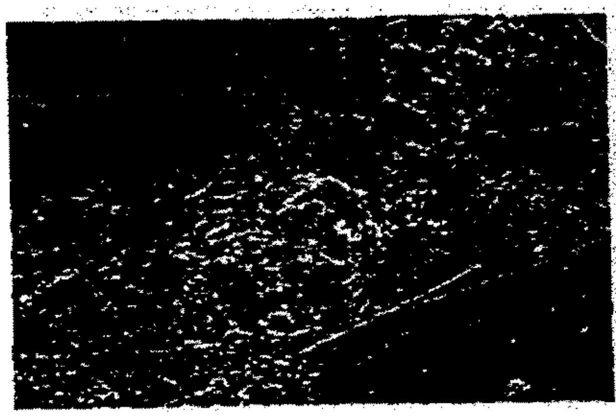


Fig. 26: Foreign body accumulation in phase contrast, HE 900×

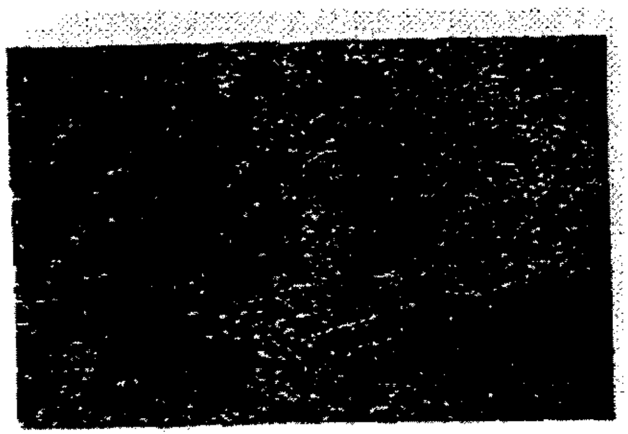


Fig. 27: Lung tissue 8 months after dust administration, EVG 225×

Relative to the control animals, no pathological delimitation is possible, except for signs of alveolitis. The regional lymph nodes also do not show reactive changes relative to the control animals.

18-month Results

After 18 months of experiment, the lung preparations of the animals treated with dust are characterized by a confluent alveolar septal widening (Fig. 28). Often, bronchial lumina filled with mucus and cell detritus are found (Figs. 29, 30), as well as inflammatory changes with involvement of the pleura, consistent with a picture of pleuropneumonia (Fig. 31). Hemosiderin-laden histiocytes are also apparent, which are peeled off in the alveolar lumen (Fig. 32). In places, collagen connective tissue strands in atelectatic pulmonary parenchyma is also apparent, which can be delimited easily from the peribronchial connective tissue (Fig. 33). The terminal bronchioli also accumulate mucus and, in places, morphonuclear inflammatory cells (Fig. 34).

The lymph nodes show hemosiderin-laden histiocytes situated mostly in the hili and medullary septa (Fig. 35, 36), which are not as pronounced in the control preparations (Fig. 37, 38).

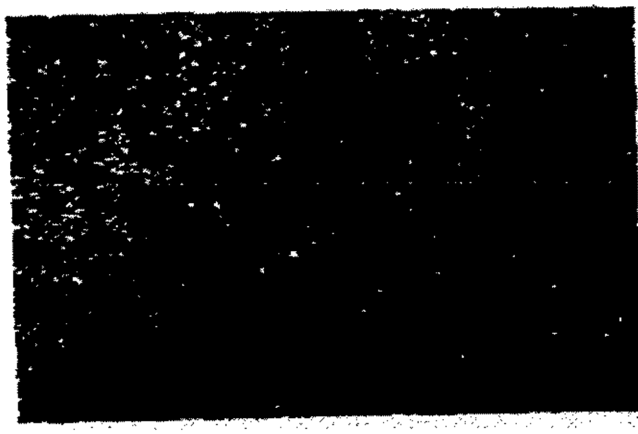


Fig. 28: Lung tissue 18 months after dust administration, HE 180×

Fig. 29: Bronchus with mucus and cell detritus, EVG 70×

Fig. 30: Peribronchial edema with obliterated bronchial lumen, EVG 70×

Fig. 31: Fibrosis of the pleura visceralis, EVG 280×

Fig. 32: Peeled-off histiocytes in the alveolar lumen, HE 2800× (oil immersion)

Fig. 33: Fibrosis trends in atelectatic pulmonary tissue,
18 months after dust administration. EVG 180×

Fig. 34: Terminal bronchioli obliterated with mucus
HE 2250× (oil immersion)

Fig. 35: Lymph node with hemosiderin-laden histiocytes
HE 280×

Fig. 36: Detail of Fig. 35, HE 1125×

Fig. 37: Lymph node of control animals after 18 months of experiment, HE 280×

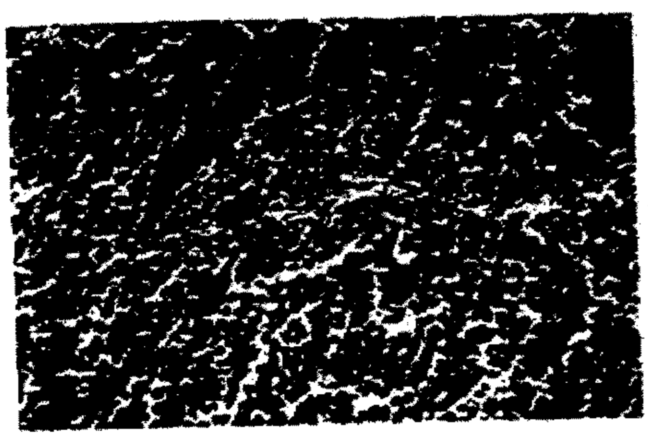


Fig. 38: Detail of a lymph node from the control population after 18 months of experiment, HE 1125×

3.3 Results of Chemical Analyses

3.3.1 Detection of Heavy Metals in Flameless Atomic Absorption Spectrometry

Whereas aluminum quickly accumulates in the lung and has reached steady state after 18 months of experiment (Fig. 39), the values in the liver are highly variable.

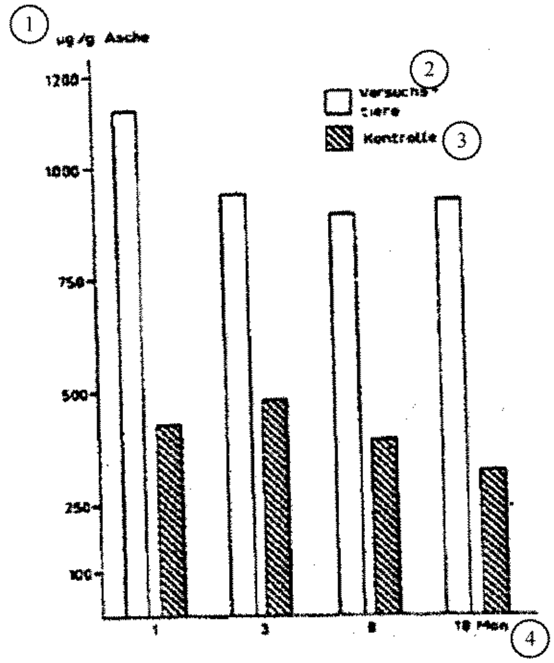


Fig. 39: Aluminum analysis in the lungs (average values)

Key:

1	µg/g ash
2	Experimental animals
3	Control
4	18 months

In places, the control animals have a greater accumulation of aluminum than the experimental animals (Fig. 40).

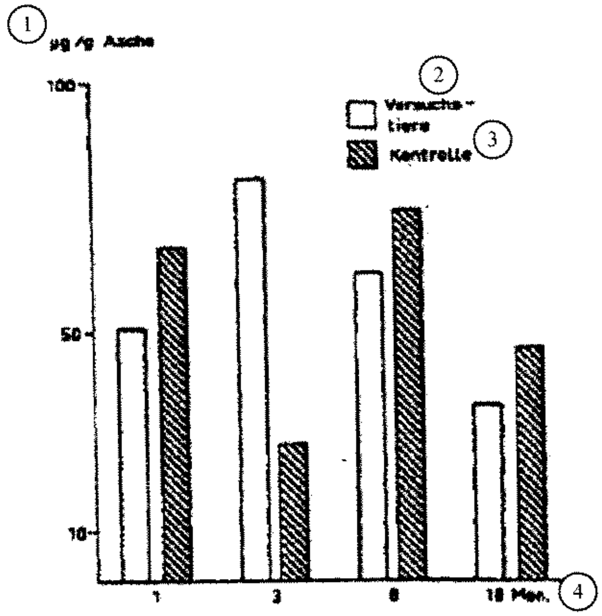


Fig. 40: Aluminum analysis in the livers (average values)

Key: 1 µg/g ash
2 Experimental animals
3 Control
4 18 months

On the other hand, the kidneys show high retention values of aluminum and rapidly diminishing values during the experiment, which correspond to those of the control animals (Fig. 41).

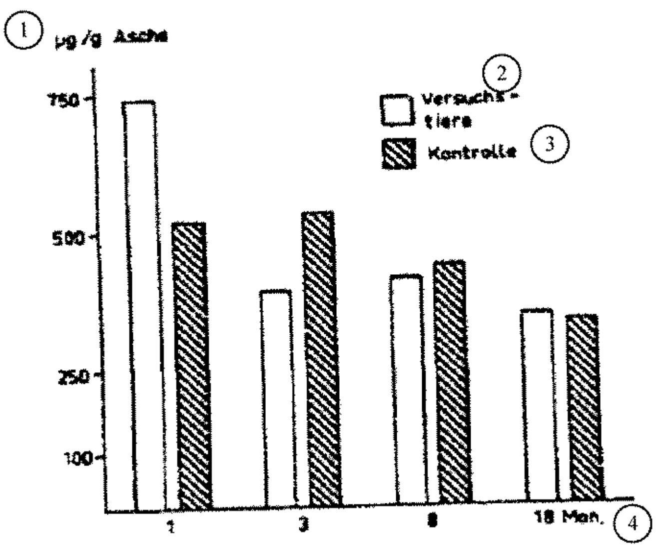


Fig. 41: Aluminum analysis in the kidneys (average values)

Key: 1 µg/g ash

2 Experimental animals
3 Control
4 18 months

Chromium shows a rapid rise at the beginning of the experiment in the lungs and a continuous drop during the experiment, but the control animals show a similar trend, so that an assertion concerning the accumulation and excretion mode is not possible (Fig. 42).

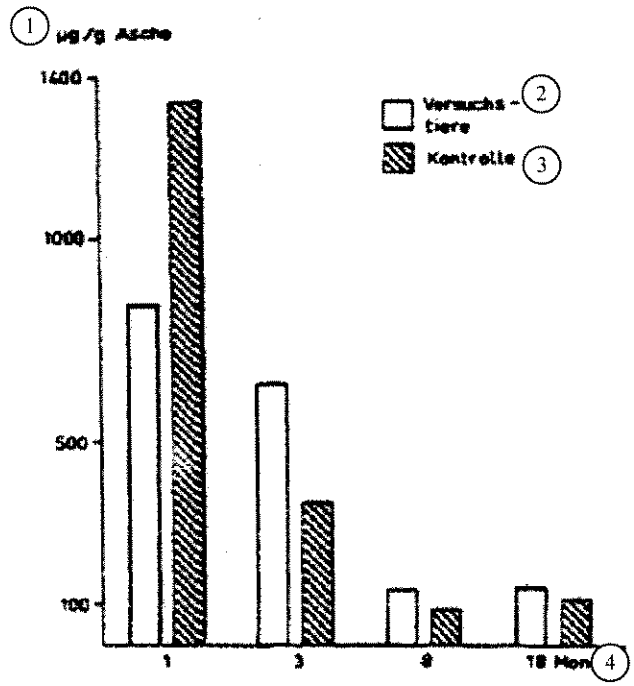


Fig. 42: Chromium analysis in the lungs (average values)

Key: 1 µg/g ash
2 Experimental animals
3 Control
4 18 months

In the liver after 30 days of experiment time, high retention of chromium is found, which has dropped to normal values already after 8 months (Fig. 43).

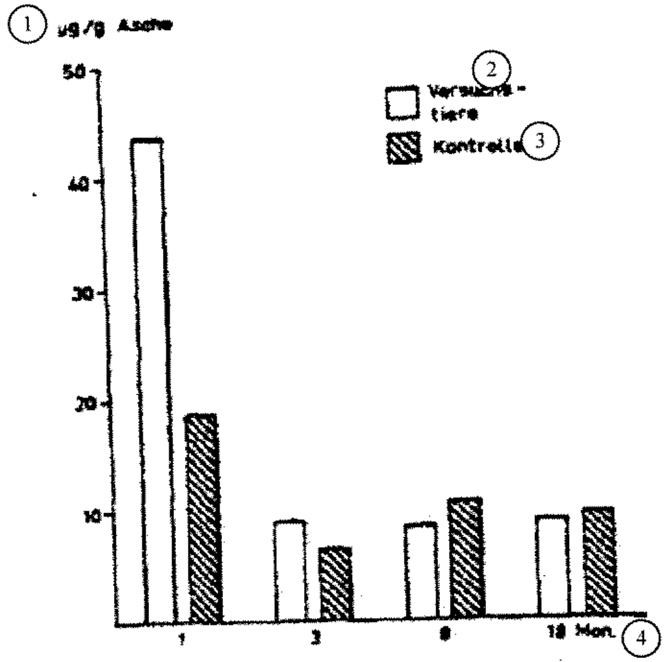


Fig. 43: Chromium analysis in the liver (average values)

Key: 1 µg/g ash
2 Experimental animals
3 Control
4 18 months

In the kidneys, the chromium analyses show scarcely usable results, since the control animals always gave higher analysis values than the experimental animals.

However, a mechanism is conceivable here that could influence excretion of chromium and another element in parallel (Fig. 44).

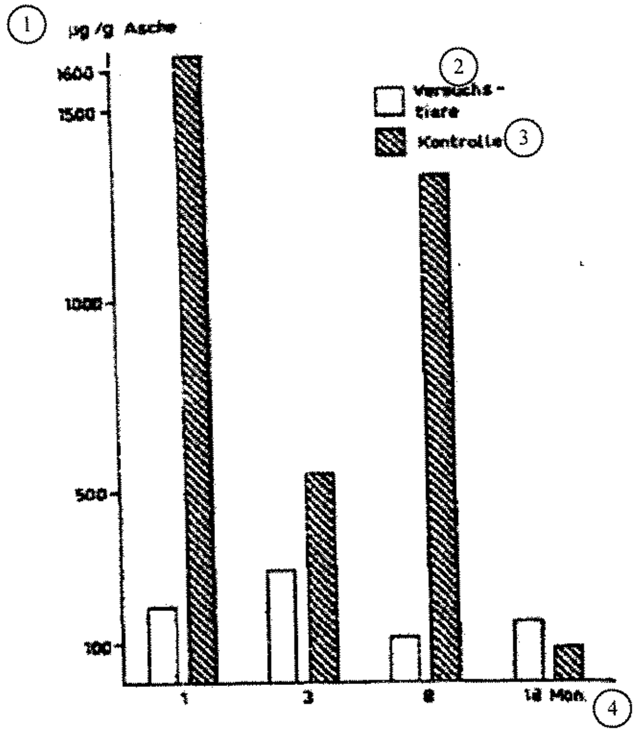


Fig. 44: Chromium analysis in the kidneys (average values)

Key: 1 µg/g ash
2 Experimental animals
3 Control
4 18 months

Nickel also shows no tendency toward accumulation in the lungs. While the maximum retention is observed after 3 months of experiment, the control values after 18 months show twice the content of nickel as the experimental animals (Fig. 45).

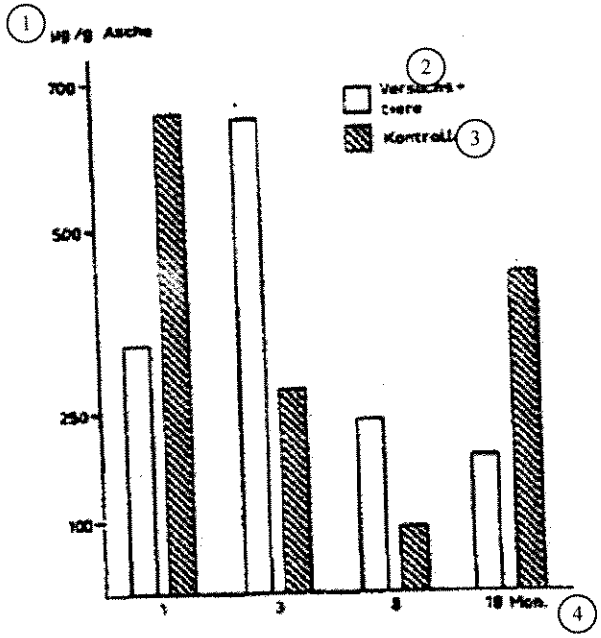


Fig. 45: Nickel analysis in the lungs (average values)

Key:
1 µg/g ash
2 Experimental animals
3 Control
4 18 months

In the liver and kidneys, nickel is already detectable one month after the beginning of the experiment in high concentrations and continuously drops during the experiment. After 18 months, the nickel content has reached the level of the control animals (Figs. 46, 47).

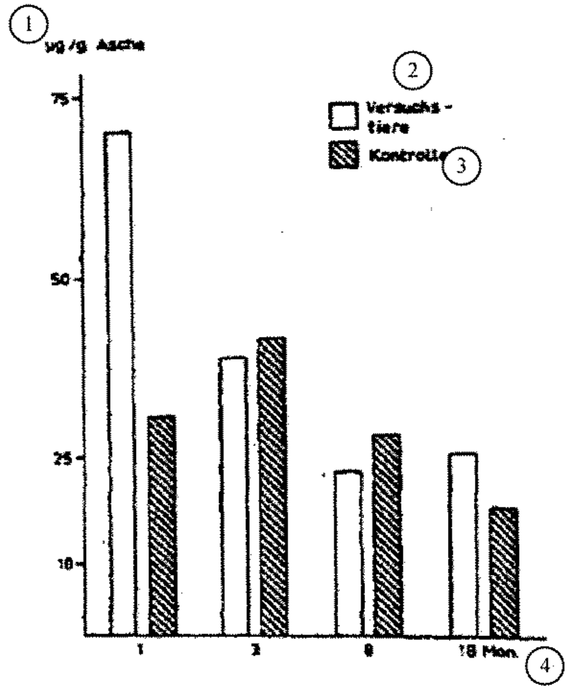


Fig. 46: Nickel analysis in the livers (average values)

Key:
1 µg/g ash
2 Experimental animals
3 Control
4 18 months

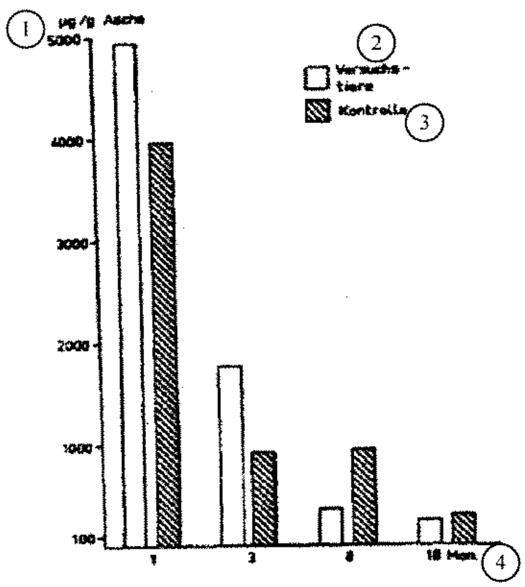


Fig. 47: Nickel analysis in the kidneys (average values)

Key:
1 µg/g ash
2 Experimental animals

3 Control
4 18 months

Lead, with a special affinity for bone substance, accumulates in the femur in delayed fashion, experiences a steady state and appears to be excreted again immediately (Fig. 48).

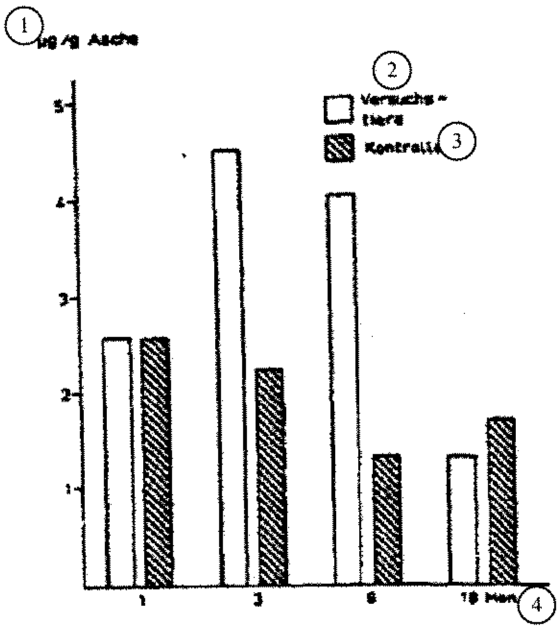


Fig. 48: Accumulation of lead in the femur (the graph represents the average values)

Key: 1 µg/g ash
2 Experimental animals
3 Control
4 18 months

The fact that the animals treated with dust show lower concentrations of individual elements at the end of the experiment than those of the control animals might be due to an overshoot reaction of the body to eliminate greater potential of foreign substances.

The average values (x) and the standard deviations (s) of the individual elements and the corresponding organs during the experiment, both of the experimental animals and the control animals, are shown in Tables 5 and 6 in the Appendix.

3.3.2 Hydroxyproline Content

The hydroxyproline content of the sample was extrapolated to 1 g dry weight of the entire lung and gave an average fraction of x = 18.8 mg hydroxyproline per gram of lung dry weight, with a standard deviation of S = 3.5 mg/g of lung dry weight after 18 months of experiment. The control population shows only slight deviations (x = 15.8 ± 5.4 mg/g).

A conclusion concerning connective tissue proliferation cannot be clearly drawn from this result, since even the control animals show an increase in hydroxyproline content relative to the previously found values (Rosmanith 1984). In the histogram (Fig. 49), the average values are graphed with the highest and lowest determined hydroxyproline value.

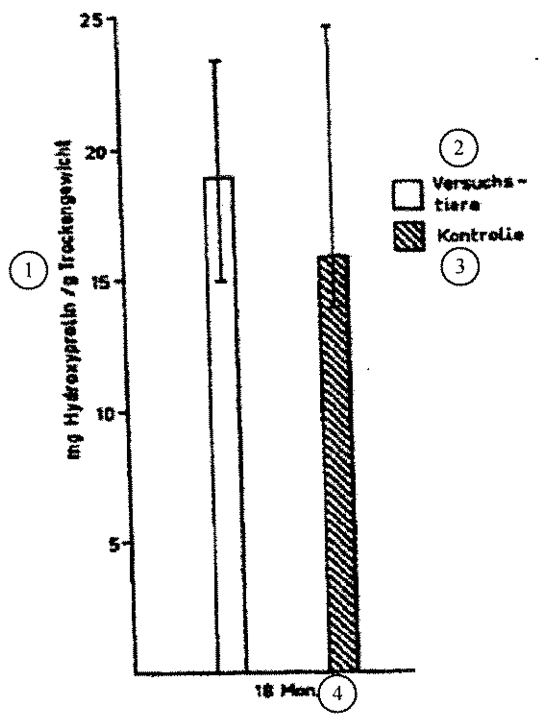


Fig. 49: Average hydroxyproline content of lungs after 18 months of experiment (average values with highest and lowest determined hydroxyproline value)

Key:

1	mg hydroxyproline/g in dry weight
2	Experimental animals
3	Control
4	18 months

4. Discussion

For an understanding of dust-related lung diseases, it must always be kept in mind that a stage generally precedes them in which the body attempts to eliminate the inhaled dust in different ways. There are two possibilities for the lungs to free itself of penetrated dust particles; the nature of the dust then dictates which mode of lung cleaning is applied: elimination via the bronchial tree or transport out via the lymph.
In this context, some comments will be made on the self-cleaning mechanism of the lungs.
The objective of self-cleaning of the lungs is to keep free the alveoli and alveolar wall, which are important for gas exchange (Otto 1970).

The bronchial mucosa lies on a mucus film, which originates from the mucus glands and deeper cells of the bronchial wall. This mucus is guided toward the mouth by the cilia of the ciliated epithelium of the bronchial mucosa and can then be removed via the intestinal tract or expectorated. With diminishing size of the dust particles and at maximum dust load, which exceeds the capacity of the self-cleaning mechanism, more dust arrives in the deeper layers of the respiratory tract, in which case the particles larger than 60 µm can penetrate into the bronchi of the lower lobe and the very fine particles (0.5-5 µm) tend to deposit in the basal parts of the upper lobes of the lung (Könn et al., 1983). The actual transfer mechanism of dust particles into the pulmonary interstitium is still very disputed. On the other hand, it is undisputed that transport occurs. According to Klosterkotter (1956) and Spencer (1977), groups of alveolar cover cells should form the base and induce an "alveolar ulcer" on this account. At this point, a direct contact between the dust particles and the interstitial tissue would be present. In the repair phase, increasingly more macrophages should appear here, which are covered by the reformed alveolar cover cells. Part of the absorbed dust remains here in the interstitium of the lungs and part is phagocytized by the macrophages and eliminated via the mucus film on the bronchi. Another part is suspended in the lymph. This cleaning means transfer of dust from the lungs to the lymph nodes. Depending on the nature and concentration of the dust, changes can occur here (Könn et al., 1983; Strumeliev 1978).
In examining the technical literature, no publications are found concerned with the tolerability of flue gas desulfurized gypsum. On the other hand, we are better informed concerning the inert nature of natural calcium dusts (Delbeck 1972). However, the results can be compared only conditionally with the results presented here, since the dust used here can have significant contaminants, because of its industrial production, for which a fibrogenic or carcinogenic effect is sometimes known or assumed.

The histologic changes in the lungs and mediastinal lymph nodes presented different pictures during the experiment: whereas after one and three months of experiment, the changes in the lungs were primarily a picture of nonspecific, lymphocyte inflammatory reaction and moderate alveolar septal widening, in the lymph nodes additional of histiocytes with hemosiderin storage was found. Phagocytized dust was no longer detectable. Preparations of this fraction showed no distinct differences relative to the control animals, so that these changes are considered to be a nonspecific foreign body reaction.

The hemosiderin accumulation, both in lung tissue and in lymph nodes, however, suggests bleeding that might be attributed to endothelial cell damage of the capillaries.

In the eight- and eighteen-month fraction, progression of the aforementioned changes is found with distinct differences relative to the control group. Tendencies toward fibrosis are found in isolated cases, mostly in the subpleural area with involvement of the visceral pleura. The presence of subpleural emphysema changes, in addition to atelectatic lung tissue, was also conspicuous.

Whether the outlined morphological changes represent a specific reaction of the elements contained in the dust, like Al, Ni and Cr, cannot be stated with final certainty. It must also be assumed that the aluminum can be assigned a protective effect with respect to development of fibrosis. Aluminum aerosols in animal experiments showed a good prophylactic and therapeutic effect in lungs altered by anthracosilicosis (Weller 1984). However, whether the concentration in the administered dust is sufficient for a protective effect also remains an open question.

There are contradictory opinions in the literature concerning the pathogenetic significance of nickel in interstitial pneumonia. Wehner (1979) could not find any significant histopathological changes in fly ash aerosol concentrated with nickel in an animal experiment, whereas Wiernick (1983) was able to demonstrate a change of alveolar macrophages after exposure to dissolved nickel in an animal experiment.

To summarize, it can be stated that the flue gas desulfurization gypsum administered intratracheally triggered a nonspecific inflammatory reaction that corresponds to an alveolitis. However, the basic scheme that will justify a diagnosis of chronic interstitial pneumonia can be recognized only with difficulty.

In the florid stage, a cellular reaction and edematous widening of the alveolar septa can be found, probably at the bottom of a capillary permeability disorder. However, distinct areas, in which the alveoli are covered with pneumocytes II, cannot be detected. This change of the alveolar epithelium, described as cuboid transformation, however, is evaluated as a characteristic morphological substrate of interstitial pneumonia (Crystal et al., 1978).

However, there are other important characteristic changes during development of chronic interstitial lung diseases that are similar to the changes found in animal experiments.

Interstitial lung diseases are characterized by chronic changes in the pulmonary parenchyma and alveolar interstitium. According to Crystal (1981), alveolitis might be assigned a pathogenetic key position here. A number of etiologically known and unknown toxins can lead to inflammation of pulmonary alveoli in disposed organisms. The type, extent and progression of subsequent lung tissue damage, however, are probably largely dependent on the number, cell type and activation stage of the effector cells that cause the alveolitis (Crystal 1981). The effector cells include macrophages, lymphocytes and granulocytes, which maintain homeostasis of pulmonary tissue in the healthy organism. However, they can be stimulated and activated by a wide variety of etiological toxins and, because of this, might have a direct effect by cytotoxicity and an indirect effect by liberation of mediators and enzymes that cause damage to lung tissue.

T-lymphocytes, activated by antigen content, mediate migration of monocytes from blood vessels into the pulmonary interstitium and their transformation to macrophages. Gadek et al. (1980) was able to demonstrate that these activated macrophages can liberate a chemotactic factor for neutrophil granulocytes. This causes accumulation and activation of neutrophils in the pulmonary interstitium. Neutrophil granulocytes have high phagocytosis capacity and are rich in hydrolases, like elastase and collagenase. If one starts from the idea that during a surface defect, an imbalance can develop between macrophages and granulocytes in favor of granulocytes, according to Hunninghake et al. (1979), the antiproteolytic system of the macrophages (bes-α_1 antitrypsin) cannot compensate for the overshoot reaction of enzyme release from the granulocytes. Owing to this relative α_1 anti-trypsin deficiency, the destructive effect of elastase can lead to destruction of the contractile elements of the intercellular substance. An emphysematic change would be the consequence.

Activation of the complement system, as well as release of vasoactive substances, like serotonin and histamine, cause throttling of capillary blood flow by edema and therefore tissue acidosis, which results in reduced cell synthesis performance. Less anti-atelectasis factors form, so that atelectatic changes would be explained.

Since invasive diagnosis has been supplemented by less invasive methods, a larger patient group has also been included with pulmonary framework diseases. With bronchoalveolar lavage (BAL), a method became available that makes it possible to quantify cells that are striking in the histologic preparation. Hunninghake et al. (1979) was able to demonstrate that in the BAL rinse liquid in healthy persons, 90% of all cells represent alveolar macrophages, 7% lymphocytes and fewer than 1% granulocytes are present. In patients with interstitial pneumonia, this cell picture was characteristically altered. Relative to healthy subjects, a distinct drop in macrophages and a distinct rise in lymphocyte population were found. Möller et al. (1984) were able to confirm these results. In their study, three different disease pictures with known and unknown etiology of interstitial pneumonia were investigated. Like Hunninghake, Möller observed a shift in favor of lymphocytes in the differential cell count. The values of the cells in the BAL rinse liquid were contrary to the results in peripheral blood.

The pathomechanism of lung framework disease might run according to the mechanism described above. However, a prerequisite would be a permanent or an intermittent stimulation of effector cells, so that alveolitis could be produced or maintained. Depending on the type, duration and extent of the stimulus, as well as the immunologic reaction of the body, alveolitis can have different quality and intensity. According to this concept, the degree of alveolitis would dictate the magnitude of the lung tissue damage.

From this standpoint, the lymphocyte infiltrations detected after dust administration in animal experiments in extensive areas of the pulmonary parenchyma must be devoted particular attention, especially since the changes were detectable even after a single dust administration. The development of chronic interstitial lung disease must therefore not be fully ruled out during long-term exposure.

However, the extent to which these relations between alveolitis and the development of chronic interstitial lung diseases can be confirmed is still a subject for future research.

5. Summary

Large combustion plants, during combustion of fossil fuels, generate flue gases with significant amounts of sulfur dioxide. This is an environmental pollutant that must be removed from the flue gases before they enter the atmosphere. Several methods are available to do this. In the Federal Republic of Germany, the lime washing method has gained acceptance, in which the sulfur dioxide is bonded to calcium and precipitates as gypsum. This so-called flue gas gypsum finds extensive use as raw material in the construction industry.

[Two sentences illegible]
The medical aspects of possible pulmonary toxic effects are demonstrated in animal experiments.

All experimental animals were administered once a dust concentration of 25 mg in 0.5 mL isotonic sodium chloride solution intratracheally. The animals were investigated at intervals of one day, and one, three, eight and eighteen months.

The right upper lobes of the lung and the mediastinal lymph nodes were evaluated histologically and the rest of the lungs, the liver, right kidney and right femur were analyzed chemically for heavy metals, and a lung, after eighteen months in experiment, was investigated for increased collagen formation.

With a light microscope, the dust was already no longer detectable after 24 h. During the experiment at 18 months, no distinct pathological reaction could be delimited relative to the control animals.

Overall, the histologic pictures of the lungs showed massive lymphocyte infiltrates with disseminated, partially confluent foci of alveolar septal widening, consistent with a picture of nonspecific alveolitis. These changes were detectable, both in the experimental animals in pronounced form and in the control animals in weakened form.
Signs of granuloma development or even connective tissue reproduction in the sense of incipient pulmonary fibrosis were not detectable in any of the histologic preparations.

Chemical analysis by flameless atomic absorption spectrometry also did not find increased components of aluminum, chromium and nickel in the parenchymatous organs, like the lungs, kidney and liver; lead showed a rapid accumulation tendency in the femur at the beginning of the experiment and elimination after 18 months of experiment time.

In the Ames mutagenicity test, the administered dust could not be clearly classified as mutagenic.

The dust that was used here can therefore be largely referred to as inert. However, this does not mean that this dust is fully safe in terms of health, since the risk of permanent or intermittent exposure is not considered in this work.
Should this dust be capable of supporting alveolitis over a certain time, the development of a chronic interstitial lung disease, as well as the hazard of malignant transformation, should not be underestimated.

6. References

Ames, B.N.; Durston, E.; Yamasaki, E.; Lee, F.D.
Carcinogens are mutagens: A simple test system combining liver homogenates for activation and bakteria for detection
Proc. Natl. Acad. Sci. USA 70, 2281-2285 (1973)

Ames, B.N.; Lee, F.D.
An improved bakterial test system for the detection and classification of mutagens and carcinogens
Proc. Nat. Acad. Sci. USA 70, 782-786 (1973)

Ames, BN.; Mc. Cann, J.; Yamasaki, E.
Methods for detection carcinogens and mutagens with the Salmonella/mammalian-microsome mutagenicity test
Mutation Res. 31, 347-363 (1975)

Ashby, J.; Styles, J.A.
Does Carcinogenic Potency correlate with mutagenic Potency in the Ames assay?
Nature, 271, 452-455 (1978)

Bakke, E.
Application of the lime/Limestone flue gas desulfurization process to smelter gases
Control Technology News 30, 1157-1160 (1980)

Bloss, W.
Sinnvolles Weiterverwenden der Endprodukte bei der Rauchgasentschwefelung
Maschinenmarkt 88, 876-878 (1982)

Bund, K.-H.
Steinkohlentag 1979
Rede des Vorstandsvors. des Gesamtverbandes "Deutscher Steinkohlenbergbau"
Steinkohlentag, Essen, 17./18. Oktober 1979

Bundes-Immissionsschutzgesetz -BImSchG-
Gesetz zum Schutz vor schädlichen Umwelteinwirkungen durch Luftverunreinigungen, Geräusche, Erschütterungen und ähnliche Vorgänge
BGBl. I S. 721, 1193 (1974)

Bundesminister des Innern (BMI)
Dritter Immissionsschutzbericht der Bundesregierung
Bundesministerium des Innern, Drucksache 10/1354 (1984)

Crystal, R.G.; Gadek, J.E.; Ferrans, V.J.; Fulmer, J.D.; Line, B.R., Hunninghake, G.W.
Interstitial lung disease: Current Concepts of pathogenesis, staging and therapy
Amer. Journal of medcine 70, 542-568 (1981)

Davis, W.T.
The retention of sulfur in fly ash from Coal-fired-boilers
Jour. air pollution Contr. Ass. 32, 395-397 (1982)

Dehnen, W.; Tomingas, R.; Pitz, R.
Untersuchungen zur mutagenen Wirkung von Schwebstoffextrakten unterschiedlich belasteter Gebiete im Ames-Test während eines Jahres
Zbl. Bakt. Hyg. I Bd. 172, 351-366 (1981)

Delbeck, N.
Zell- und Gewebeschädigung durch Calciumstäube
Diss. RWTH Aachen 1972

Dünger aus Gas
Energie und Technik 30, 279-284 (1978)

Dünger aus Kraftwerksabgasen
Industrie-Anzeiger-Umweltschutz 103, 49-50 (1981)

Einbrodt, H.J.
Quantitative und qualitative Untersuchungen über die Staubretention in der menschlichen Lunge
Beitr. Silikose-Forsch. H. 87, 1-105 (1965)

Einbrodt, H.J.; Arnold, M.; Keltsch, H.-J.
Über die Staubverteilung in menschlichen Lungen nach jahrelanger Staubabkehr
Arch. Gewebepath. Gewerbehyg. 19, 370-376 (1962)

Einbrodt, H.J.; Metze, H.; Keltsch, H.-J.
Quantitative Untersuchungen zum lymphogenen Abtransport des exogenen Staubes aus der menschlichen Lunge mit langer Expositionszeit
Beitr. Silikose-Forsch. S-Bd. Grundfragen Silikose-Forsch. Bd. 5, 437-446 (1963)

Einbrodt, H.J.
persönliche Mitteilung 1984

Forth, W.; Hentschler, A.; Rummel, W.
Pharmakologie und Toxikologie
3. Auflage, S. 40 ff.
B.I.-Wissenschaftsverlag Wien, Zürich 1978

Gadek, J.E.; Hunnighake, G.W.; Zimmermann, R.; Crystal, R.G.
Regulation of release of the Alveolar Macrophage-derived Chemotactic Factor
Amer. Rev. Respirat. Dis. 121, 723-733 (1980)

Gerking, E.
Vom sauren Regen in die Kostentraufe
Energie, 31, 252-259 (1979)

Gerking, E.
Emission oder Immission?
- Überlegungen zu einem volkswirtschaftlich optimalen
Konzept zum rauchgasseitigen Immissionsschutz -
Energie 30, 261-274 (1978)

Gräfeling, N.
Rauchgasentschwefelung
Verfahren, Endprodukte, Märkte
Energie 30, 415-427 (1978)

Gräfeling, N.
Mit Kalkstein zu Gips
Energie 31, 409-414 (1979)

Gutberlet, H.; Stappert, S.
Chem. Probleme, Inbetriebnahme und Erfahrungen mit der
Rauchgasentschwefelungsanlage in Scholven
VGB-Kraftwerkstechnik 61, 849-856 (1981)

Hamm, H.; Höller, R.
Ein wirtschaftliches Verfahren zur Rauchgasentschwefelung
nach dem K-R-C-Verfahren
Chemie-Technik 11, 211-215 (1982)

Hamm, H.
Rauchgasentschwefelung und Restentsorgung von Kraftwerken
Industrie-Anzeiger 24 (1984)

Hayatsa, M.
Mutagenicity of chalks
Mutation Res. 124, 1-7 (1983)

Huninghake, G.W.; Gadek, J.E.; Kawanami, O.; Ferrans, V.J.; Crystal, R.G.
Inflammatory and Immune Processes in the Human lung in Health and Disease: Evaluation by Bronchoalveolar Lavage
Amer. Jour. Pathology 97, 149-206 (1979)

Kerr, A.R.
There is more to "Acid Rain" than rain
Science, 211, 692-693 (1981)

Klosterkötter, W.
Tierexperimentelle Untersuchungen über die Lungenreinigung
Beitrag Silikose-Forsch. S-Bd., Grundfragen Silikose-Forsch. Bd. 2, 537 (1956)

Könn, G.; Schejbal, V.; Oellig, W.-P.
Pneumokoniosen. In: Pathologie der Lunge Bd. 16/II, 647-778
Hrsg.: Doerr, W.; Seifert, G.; Uehlinger, E.
Springer Verlag Berlin, Heidelberg, New York 1983

Lahmann, E.
Die Technische Anleitung zur Reinhaltung der Luft 1983
Gesundheits-Ingenieur 104, 217-220 (1983)

Langmer, G.; Glitz, A.
Vorschriften zur Reinhaltung der Luft - Techn. Anleitung zur Reinhaltung der Luft (TA-Luft) - in der Fassung vom 4. Febr. 1983 - Bundesanzeiger 1983

Löffler, G.; Petrides, P.E.; Weiss, L.; Harper, H.A.
Physiologische Chemie
2. Auflage, 801-814, 1979
Springer-Verlag Berlin, Heidelberg, New York 1979

Lukas, W.
Wirtschaftliche Aspekte bei der Verwertung von Rauchgasgips
Umwelt 11, 332-336 (1981)

Mattern, J.; Greim, H.
Report of a workshop on Bacterial Mutagenicity Test Systems
Mutation Res. 53, 369-378 (1978)

Mileman, N.
Acid Precipitation
Enviromental Sci. and Technology 15, 1119-1153 (1981)

Möller, D.
Das Verhältnis von anthropogener zu natürlicher globaler Schwefelemission
Z. ges. Hyg. 28, 11-15 (1982)

Müller, St.; Kramer, H.; Bergmann, K.-Ch.; Wiesner, B.; Grollmuss, H.; Umger, U.; Christ, R.; Eckert, H.
Lymphocytenpopulation in der bronchoalveolären Spülflüssigkeit bei einigen interstitiellen Lungenerkrankumgen
Z. Erkrank. Atm. Organe 163, 140-145 (1984)

Nolte, D.
Zur bronchomotorischen Reizbarkeit durch Umweltfaktoren
Umweltmedizin 1/73, 8-11 (1973)

Otto, H.; Büchner, F.; Cottier, H.; Grundmann, E.; Holle, G.; Letterer, E.
Die Atmungsorgane. In: Handbuch der allg. Pathologie III/4, 1-175
Hrsg.: Altmann, H.-W.; Büchner, S.
Springer Verlag: Berlin, Heidelberg, New York 1970

Pietrzeniuk, H.-J.
Verwertung der Endprodukte aus der Rauchgasentschwefelung
FIZ-Fachberichte Rohstoff-Engineering 105, 506-508 (1981)

Poirier, L.A.; de Serres, F.J.
Initial National Cancer Institude Studies on Mutagenesis
as a Prescreen for chemical Carcinogenesis
Jour. Nat. Cancer Inst. 62, 919-926 (1979)

Purchase, I.F.H.
Evaluation of six short term tests for detecting organic
chem. carcinogens and reccommendations for their use
Nature 264, 624-627 (1976)

Rosenkranz, H.S.; Poirier, L.A.
Evaluation of the Mutagenicity and DNA-Modifying Activity
of Carcinogens and Noncarcinogens in Microbiolog. Systems
Journ. Nat. Cancer Inst. 62, 873-891 (1979)

Rosmanith, J.; Reisner, M.T.R.; Prajsnar, D.
Die Beziehungen zwischen der Zusammensetzung des Feinstaubes, der retinierten Staubmasse und der fibrotischen Reaktion in Lungen und Lymphknoten der Ratte beim Intratrachealtest
Silikosebericht Nordrhein-Westfalen Bd. 13, 241-249 (1983)

Rosmanith, J.
Persönliche Mitteilung 1984

Schmidt, W.
Die Praxis der Atomabsorptionsspektralphotometrie
Fa. Beckmann, München 1978

Schlipköter, H.W.
Eigenschaften und Wirkung von Staubaerosolen unter besonderer Berücksichtigung der Gewerbestäube.
Habilitationsschrift, Düsseldorf 1955

Sequeira, R.
Acid rain: An Assessment based on Acid-Base considerations
Journ. air Pollution Control Ass. 32, 241-245 (1982)

Spencer, H.
Pathology of the lung
Pergamon Press, 3. Auflage, Oxford 1977

Stegemann, H.
Mikrobestimmung von Hydroxyprolin mit Chloramin-T und p-Dimethylaminobenzaldehyd
Hoppe-Seylers Z. f. physiolog. Chemie, Bd. 311, 41-45 (1958)

Strumeliev, St.
Abwehrmechanismen der Lunge
Z. Erkrankungen Atm.-Org. 151, 262-267 (1978)

Tanner, R.L.; Leaderer, B.P.; Spengler, J.D.
Acidity of atmospheric aerosols, a summary of data concerning their chemical nature and amounts of acid
Environm. Science and Technology 15, 1150-1153 (1981)

Tiedemann, G.; Einbrodt, H.J.
Zur Mutagenität anorganischer Arsenverbindungen
Wissenschaft und Umwelt 3, 170-173 (1982)

Umweltbundesamt (UBA)
Dreizehnte Verordnung zur Durchführung des Bundesimmissionsschutzgesetztes - Verordnung über Großfeuerungsanlagen -
BGBl. I, 719-730 (1983)

Webner, A.P.
Akute und subchron. Inhalationsexposition mit Nickel angereichertem Flugasche-Aerosol bei Hamstern
Environm. Res. 15, 355-370 (1979)

Weiler, H.
Mit Kalk und Kreide
Energie 32, 29-32 (1980)

Weller, W.
Aluminiumbehandlung der Anthrakosilikose - Experimentelle Grundlagen -
Bundesanstalt für Arbeitsschutz (1984)

Welz, B.
Atom-Absorptions-Spektroskopie
Verlag Chemie, Weinheim 1972

Werner, H.
Verunreinigung der Atmosphäre durch SO_2
Energie 19, 200-201 (1967)

Wiernick, A.
Rabbit lung after inhalation of solube Nickel - Effects on alveolar macrophyges -
Environm. Res. 30, 129-141 (1983)

Wirsching, F.
Trocknung und Agglomerierung vom Rauchgasgips
Umwelt 6, 435-438 (1983)

Wirsching, F.
Zement, Kalk, Gips. In: Chemische Technologie, Bd. 3, Anorganische Technologie II 261-275
Carl Hanser Verlag München Wien 1983

7. Appendix

Experiment Tables

Table 1: Global emission of SO_2 in 10^6 t S/a

Source: Möller (1982)

	1 Steinkohle	2 Braunkohle	3 Erdöl	4 Sonstiges[1]	5 Gesamt
	2.4	0.0	0.0	0.1	2.5
1870	3.6	0.1	0.0	0.2	3.9
1880	5.5	0.2	0.0	0.3	6.1
1890	8.4	0.3	0.1	0.5	9.3
1900	12.5	0.6	0.2	0.7	14.1
1910	18.8	0.9	0.5	1.2	21.4
1915	19.0	1.0	0.6	1.7	22.3
1920	21.2	1.3	1.0	2.1	25.6
1925	21.1	1.6	1.6	2.2	25.7
1930	24.2	1.7	2.1	2.2	27.6
1935	19.4	1.6	2.4	2.2	25.2
1940	24.2	2.6	3.1	3.6	33.5
1945	21.2	1.6	3.7	3.2	28.7
1950	25.8	3.0	5.6	3.8	38.2
1955	24.9	4.5	8.2	4.4	42.0
1957	27.7	5.0	9.4	4.7	46.3
1959	30.2	5.2	10.4	4.8	50.6
1961	30.4	5.6	11.8	5.2	52.2
1963	31.2	6.0	13.8	5.1	56.1
1965	31.8	6.2	16.0	5.3	59.3
1967	31.5	6.1	18.6	5.0	61.2
1969	31.3	6.4	21.9	5.4	65.0
1971	33.5	6.8	25.4	5.3	71.0
1973	33.6	6.9	29.4	5.8	75.7
1975	35.0	7.2	28.1	5.8	76.1
1977	37.2	7.7	30.4	6.0	81.3
1985	41.0	9.5	32.0	7.5	90.0
2000	48.0	12.0	30.0	10.0	100.0

[1] Copper, lead and zinc metallurgy, sulfuric acid production

Key:

1	Bituminous coal
2	Brown coal
3	Petroleum
4	Other [1]
5	Total

Table 2: SO_2 annual emissions according to emitter groups in the Federal Republic of Germany

Source: Federal Ministry of the Interior, 1984

			1966	1970	1974	1978	1982
1	Gesamtemission in 10^6 t/a		3.2	3.6	3.6	3.4	3.0
2	Anteile der Emittenten in v. H.	Verkehr 3	3.1	3.2	3,4	3,7	3,4
		Haushalte 4	19.9	18.6	15,3	13,4	9,3
		Industrie 5	35.7	32,3	30,0	27,8	25.2
		Kraft- und Heizwerke 6	41,3	45,9	51,3	55.1	62,1

Key:
1 Total emission in 10^6 t/a
2 Fractions of emittance in %
3 Traffic
4 Household
5 Industry
6 Power and heating plants

Table 3: Emission limit values of the 13th Federal Immission Control Ordinance

Source: Federal Environmental Office 1983

1 Schadstoffe	2 Neuanlagen	3 Altanlagen
4 Staub (mg/m³)	8 Kohle: 50 (§ 3)	ab 1.7.1988 Braunkohle: 80 (§ 17) andere feste Brennstoffe: 125 10
5 Kohlenmonoxid (mg/m³)	9 Kohle: 250 (§ 4) Oel: 175 (§ 9) Gas: 100 (§14)	9 Kohle: 250 (§ 4) Oel: 175 (§ 9) Gas: 100 (§14)
6 Stickstoffoxide (mg/m³)	9 Kohle: 800 (§ 5) Oel: 450 (§10) Gas: 350 (§15)	ab 1.7.1988 Steinkohle: 1300 (§19) Oel: 700 Gas: 500 andere feste Brennstoffe: 1000 11
7 Schwefeldioxid (mg/m³)	9 Kohle: 400 (§ 6) Oel: 400 (§11) Gas: 35 (§16)	über 300 MW$_{therm.}$ ab 1.7.1988 wie Neuanlagen (§20) 12

Key:
1 Pollutants
2 New installations
3 Old installations
4 Dust
5 Carbon monoxide
6 Nitrogen oxide
7 Sulfur dioxide

8	Coal
9	Coal Oil Gas
10	From 7/1/1988 Brown coal Other solid fuels
11	From 7/1/1988 Bituminous coal Oil Gas Other solid fuels
12	Above 300 $MW_{therm.}$ From 7/1/1988 Like new installations (§ 20)

Table 4: Temperature-time program during flameless atomic absorption spectrometry for the elements being investigated

	Pb	Al	Ni	Cr
1 Wellenlänge (nm)	283.3 9	309.3 10	232.0	357.9 1
Rohr-Typ	Low Platf.	Normal-Rohr	Pyro-R 11	Pyro-R
Spaltbreite (nm)	0.7	0.7	0.2	0.7 7
Meßarten-Signal	7 absolut	absolut	absolut	absolut
Mode	kontin. 8	kontin. 8	kontin. 8	kontin.
Recorder	7 absolut	absolut	absolut	absolut 7
Meßzeit (sec.)	1	1	1	1
Background-Corr.	AA-BG	AA	AA-BG	AA-BG
12 Schreiber (20/mm)	10 mV	10 mV	10 mV	10 mV
Drucker	*	*	*	*
2 Step 1 Trocknung:				
Temp. (°C)	90	110	100	120
Ramp-time	10	10	40	30
Hold-time	20	40	60	30
3 Step 2 therm. Zersetzung:				
Temp. (°C)	120	700	350	600
Ramp-time (s)	5	1	20	20
Hold-time (s)	10	15	10	30
4 Step 3 therm. Nachbehandl.:				
Temp. (°C)	450	1350	1300	1500
Ramp-time (s)	5	1	5	10
Hold-time (s)	10	5	50	40
5 Step 4 Atomisierung:				
Temp. (°C)	1800	2700	2600	2650
Ramp-time (s)	0	0	0	1
Hold-time (s)	3	3	3	5
Recording	*	*	*	*
Read	*	*	*	*
Gasflow (ml Ar/min)	30	40	30	60
6 Step 5 Selbstreinigung				
Temp. (°C)	2600	2700	20	2650
Ramp-time (s)	1	1	1	1
Hold-time (s)	2	5	5	2
Probenmenge (µl)	30	10	50	20
Anzahl der Messungen	2	3	2	3

Key:

1	[illegible]
2	Step 1

	Drying
	Temperature
	Ramp time
	Hold time
3	Step 2
	Thermal decomposition
	Temperature
	Ramp time
	Hold time
4	Step 3
	Thermal final treatment
	Temperature
	Ramp time
	Hold time
5	Step 4
	Atomization
	Temperature
	Ramp time
	Hold time
	Recording
	Read
	Gas flow (mL Ar/min)
6	Step 5
	Self-cleaning
	Temperature
	Ramp time
	Hold time
	Sample amount
	Number of measurements
7	Absolute
8	Continuous
9	Low platform
10	Normal tube
11	Pyro tube
12	Printer

Table 5: Aluminum, chromium, nickel and lead content in investigated organs one, three, eight and eighteen months after dust administration. Average values and standard deviations are stated.

3	4	5	6	7	8
9	1	1120.2 ± 119.5	662.4 ± 366.9	343.6 ± 96.6	
	3	962.8 ± 47.2	650.3 ± 50.7	652.6 ± 241.9	
	8	690.4 ± 169.0	139.0 ± 35.5	230.0 ± 120.1	
	18	926.4 ± 231.2	146.5 ± 13.5	169.5 ± 37.8	
10	1	58.7 ± 26.0	43.9 ± 27.5	70.8 ± 13.2	
	3	81.3 ± 59.1	9.1 ± 2.9	38.4 ± 23.4	
	8	62.7 ± 16.6	6.5 ± 4.8	22.4 ± 18.3	
	18	39.6 ± 7.4	9.0 ± 2.1	25.1 ± 13.8	
11	1	342.4 ± 369.7	200.7 ± 59.2	4953.1 ± 4001.4	
	3	390.3 ± 43.4	397.8 ± 111.6	5169.5 ± 1860.1	
	8	413.6 ± 87.0	122.8 ± 40.5	364.2 ± 248.2	
	18	348.2 ± 48.4	155.7 ± 11.1	234.6 ± 169.5	
12	1				2.6 ± 1.2
	3				4.3 ± 1.0
	8				6.1 ± 2.8
	18				1.6 ± 0.2

Key:
1 Time
2 Elements [illegible] mg/g of ash
3 Organs
4 Months
5 Aluminum
6 Chromium
7 Nickel
8 Lead
9 Lung
10 Liver
11 Kidneys
12 Femur

Table 6: Aluminum, chromium, nickel and lead content of investigated organs of the control population

3	4	5	6	7	8
9	1	426.2 ± 54.7	1200.7 ± 285.2	668.0 ± 132.[illegible]	
	3	480.8 ± 111.2	354.2 ± 162.4	283.9 ± 40.1	
	8	393.1 ± 53.5	92.6 ± 29.8	91.0 ± 41.6	
	18	317.7 ± 96.7	122.4 ± 75.[illegible]	442.6 ± 359.4	
10	1	40.7 ± 27.[illegible]	16.7 ± 4.1	16.4 ± 10.4	
	3	37.[illegible] ± 7.6	[illegible] ± 6.3	41.2 ± 29.4	
	8	34.1 ± 42.2	18.7 ± 4.6	[illegible] ± 12.5	
	18	47.2 ± 8.3	4.7 ± 2.3	18.2 ± 7.5	
11	1	520.6 ± 95.6	1643.6 ± 1249.[illegible]	1962.4 ± 2346.5	
	3	437.6 ± 74.4	549.7 ± 421.4	917.8 ± 480.2	
	8	642.6 ± 130.5	1124.7 ± 605.5	939.1 ± 223.[illegible]	
	18	339.9 ± 64.2	65.6 ± 10.8	292.5 ± 98.[illegible]	
12	1				2.6 ± 3.4
	3				2.2 ± 1.0
	8				1.4 ± 0.6
	18				[illegible] ± 1.1

Key:	1	Time
	2	Elements [illegible] mg/g of ash
	3	Organs
	4	Months
	5	Aluminum
	6	Chromium
	7	Nickel
	8	Lead
	9	Lung
	10	Liver
	11	Kidneys
	12	Femur

CURRICULUM VITAE

On October 23, 1952, I was born as the eldest son of farmer Anton Bartmann and his wife Hildegard (nee Weitekamp) in Marsberg-Essentho in Westphalia.
I am a German citizen and belong to the Roman Catholic Church.
After nine years of public school, I completed three years of agricultural instruction in my parents' operation, which I took over in May 1970, and have managed since then as independent farmer.
Because of the structural changes in German agriculture, I first attended the Technical School for Engineering, Agriculture and Horticulture in Paderborn from 1971-1972, with a Technical University diploma, and then completed Westphalia College in Paderborn, where I graduated on June 30, 1975.
From October 1, 1975 to September 30, 1977, I served as a sanitation engineer with the army.

In October 1978, I was accepted for medical studies at RWTH Aachen, where, in September 1980, I passed the Physician's Preliminary Examination and, in October 1984, the Physician's Examination. On October 8, 1984, I was certified as a physician.

In January 1985, I married my wife, Viktoria (nee Dressler). Since March 1, 1985, I have been working in continuing medical education as an Assistant Physician at Luisen Hospital in Aachen, initially in the Radiology Department and later in the Department of Vascular Surgery. In August 1985, our daughter, Dorothea Viktoria was born.

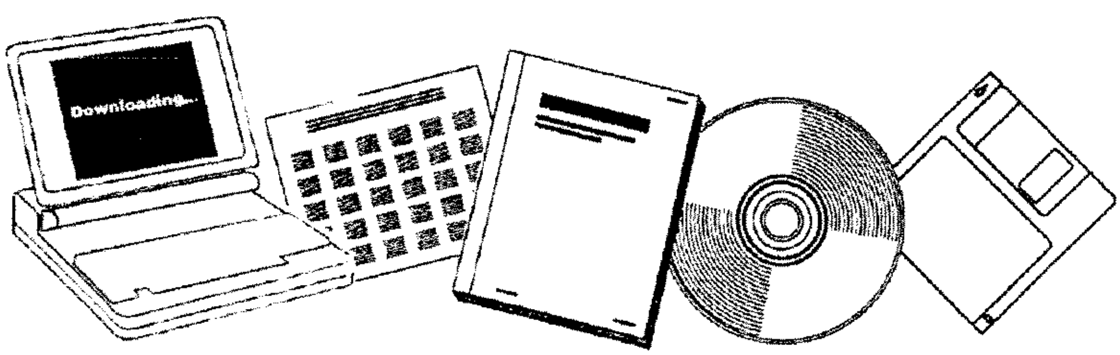
ATTACHMENT F

MUTAGENIC EFFECTS AND GYPSUM

RIKINPOISTOTUOTTEIDEN JA KIVIHIILEN LENTOTUHKAN LIUKOISUUDESTA JA TOKSISUUDESTA. (LEACHABILITY AND TOXICITY OF FLUE GAS DESULPHURIZATION PRODUCTS AND COAL FLY ASH)

IMATRAN VOIMA OY, HELSINKI (FINLAND)

1991



[Finnish original of next page]
[English transliteration of previous page]

Julkaisija-Utgivare-Published by

IMATRAN VOIMA OY

Asiakirjan koodi-K-J-Code: IVO-B-12/91

Asiakirjan päivämäärä-Datum-Date: 11.11.1991

Tekijä(t)-Författare-Author(s): Tuija Siitonen

Projektin nimi-Projektets namn-Name of project: ENDDL-PROJECT

Toimeksiantaja-Uppdragsgivare-Commissioned by: IVO

Nimeke-Namn-Title

Leachability and toxicity of flue gas desulphurization products and coal fly ash

Tiivistelmä-Referat-Abstract

In flue gas desulphurization processes of coal-fired power plants great amounts of solid wastes and fly ash are formed. The composition of these wastes is mostly dependent on the coal burned, combustion conditions and the quality of the absorbent used in desulphurization process. The amounts of different trace elements are generally smaller in desulphurization products than in fly ash. Greatest amounts of different trace elements are accumulated to the sludge from the waste water process.

The main dissoluble species are sulphates, calsium, chlorides, sodium and potassium. The leachability of boron is higher from the fly ash than from other wastes. Other high measured contents are chromium in fly ash and wet-dry desulphurization product and arsenic and mercury in sludge.

Fly ash is found mutagenic in toxicity tests. Fgd-gypsum is not mutagenic. Leaching waters of fly ash, sludge and product of wet-dry process are acutely toxic to water flea Daphnia magna. Leaching water of fgd-gypsum is not toxic according to the standard test method.

Avainsanat-Nyckelord-Key words

Fgd (Flue gas desulphurization) -product, coal fly ash, leachability, toxicity

ISSN ja avainnimeke-Nyckelnamn-Key name: 9782-9221 IVO R&D -notes

ISBN: 951-8928-73-8

Kieli-Språk-Language: Finnish

Kokonaissivumäärä-Sidantal-Number of pages: 60 +app. 4 p.

Luottamuksellisuus-Konfidentiell-Confidentiality: public

Jakaja-Utdelad av-Distributed by: IMATRAN VOIMA OY

Tarkastanut-Inspekterad av-Checked by: Ulo Kallner

TABLE OF CONTENTS

1 INTRODUCTION

In coal power plants, various kinds of solid wastes arise. A significant portion of the amount of the wastes is in the form of fly ash, which is separated with electric filters. In Finland, the amount of fly ash produced is about 400,000 tons per year. Fly ash is used in the construction industry, among other things, in the production of cement as an additive and filler for concrete.

When the emission restrictions set by the Desulfurization Law took effect in Finland in 1994, several desulfurization plants were placed in use. Several hundred thousand tons of solid waste are formed annually as their final product. The composition of desulfurization products varies according to the technique used. The final product of desulfurization based on the wet method is pure gypsum in the best case, with which the use of natural gypsum can be replaced, for example in the production of plasterboards for the construction industry. The product from the semi-dry method contains more sulfite, unreacted calcium compounds, and other impurities; it can be used, e.g., in earth construction and in the production of concrete. The final product from the Lifac method in use in the Inkoo power plant also contains the formed fly ash; in other words, it consists of silicon, aluminum, and iron compounds in addition to sulfur and calcium compounds. The use of the Lifac product has been studied, for example, in road beds.

Solid wastes formed in power plants can cause problems because of their large quantities. The products must be stored, transported, and sorted. In all phases, the health and safety of workers must also be taken into consideration, as well as not damaging the environment. This should be guaranteed by investigating the chemical and physical characteristics of fly ash and desulfurization products and by studying the health risks caused by different exposure methods with the aid of toxicity tests. By using this information, correct handling and dumping methods can be developed that are as risk-free as possible.

The purpose of this investigation was to study the toxicity of coal fly ash and various desulfurization products by using results found in the literature and having toxicity tests made on the samples obtained. The object of interest was especially the environmental damage in the form of seepage waters caused by dumping materials.

2 DESULFURIZATION PRODUCTS AND FLY ASH

2.1 Origin and composition of desulfurization products

Desulfurization by the wet method

In the wet or gypsum method, a calcium-based wash sludge is sprayed into smoke gases in the washer. The sulfite-sulfate sludge formed in consequence of reaction of limestone and sulfur dioxide is acidified with air in such a way that the product is pure gypsum, calcium sulfate. The gypsum is washed of chlorides, etc., and dried. In the process implemented in the gypsum method, there is an effective separation of fly ash and possibly other additional cleanings. The so-called wastewater removed from the water arising from washing gypsum and recycled wash water is treated in wastewater purification plants, in which solid materials are removed, including heavy metals. Desulfurization gypsum corresponds to natural gypsum in its chemical characteristics.

[figure not in source document]
Other ($CaSO_3$, $CaCO_3$, Fe, Al, Si, etc.), 5%
Calcium sulfate, 95%
Figure 1. Composition of gypsum by the wet method.

Desulfurization by the semi-dry method

In the semi-dry method, a finely divided alkaline sludge is sprayed into the hot gas mixture in a separate reactor; a calcium-hydroxide sludge prepared from calcium oxide and water is used most commonly as the sludge. The amount of sludge is adjusted so that the entire quantity of water contained in it has time to evaporate, in which case the reactor has a so-called dry base. The product formed is separated by an electric or bag filter. In the method, there is often a pre-separation of fly ash. The product of the semi-dry method is finely divided.

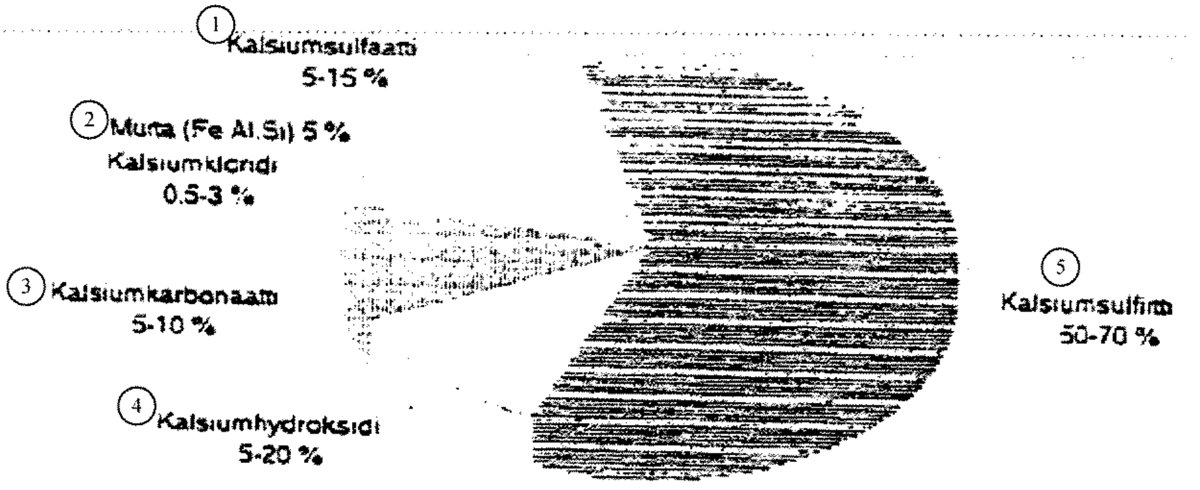


Figure 2. Composition of final product from the semi-dry desulfurization method

Key:	1	Calcium sulfate, 5-15%
	2	Other (Fe, Al, Si) 5%
		Calcium chloride, 0.5-3%
	3	Calcium carbonate 5-10%
	4	Calcium hydroxide, 5-20%
	5	Calcium sulfite, 50-70%

Desulfurization by the Lifac method (injection method)

In the Lifac method, finely ground limestone is injected into the combustion chamber of the boiler. The calcium oxide formed reacts with sulfur dioxide, at which time calcium sulfite and calcium sulfate are formed as a result of acidification. The injection product travels along with the smoke gases through an air preheater to an activation reactor, in which the smoke gases are moistened. At this time, unreacted calcium oxide from the combustion chamber is quenched to calcium hydroxide, which reacts with remaining sulfur dioxide. The final product is separated with an electric filter

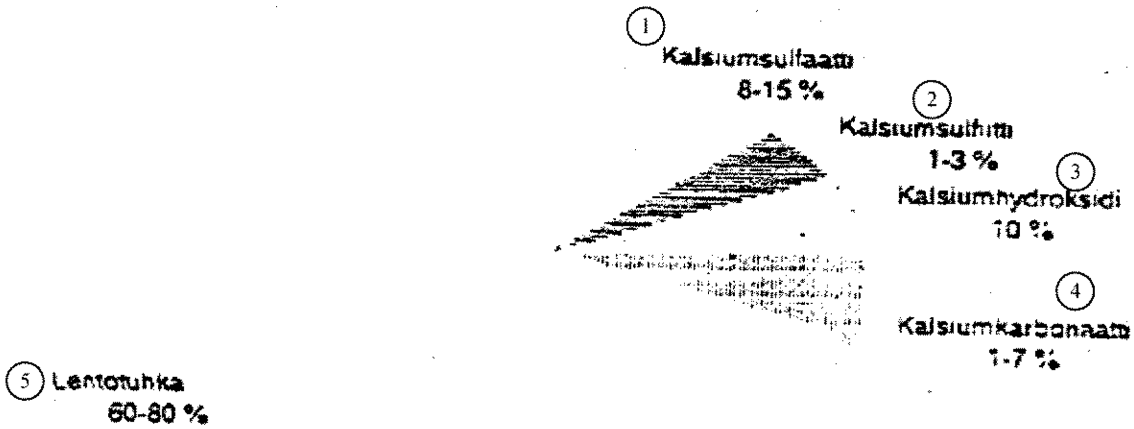


Figure 3. Composition of the Lifac product

Key:
1 Calcium sulfate, 8-15%
2 Calcium sulfite 1-3%
3 Calcium hydroxide, 10%
4 Calcium carbonate, 1-7%
5 Fly ash, 60-80%

2.2 Composition of fly ash

In Finland, about 350-400,000 tons of coal fly ash are formed annually. Fly ash consists mostly of spherical particles of various sizes and of small needle-shaped crystals. The grain size of fly ash varies between 2 and 400 μm, which corresponds most closely to silt from mineral soils.

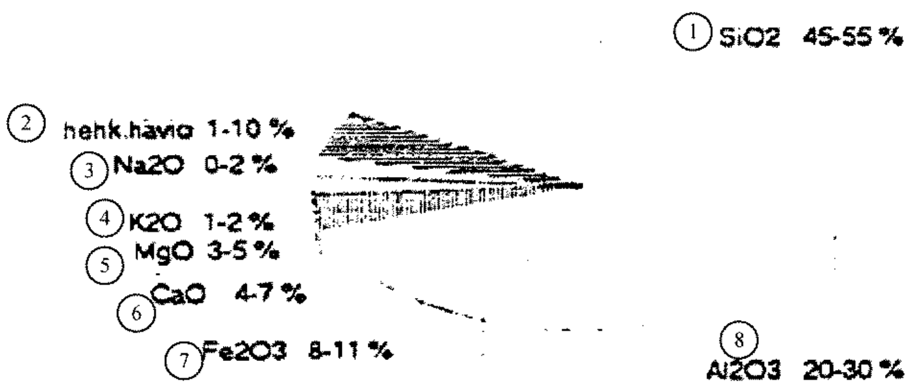


Figure 4. Composition of coal fly ash

Key:
1 SiO_2, 45-55%
2 evaporation loss, 1-10%
3 Na_2O, 0-2%
4 K_2O, 1-2%
5 MgO, 3-5%

6 CaO, 4-7%
7 Fe_2O_3, 8-11%
8 Al_2O_3, 20-30%

2.3 Comparison of elements in various samples

The final products from the different desulfurization methods contain varying amounts of heavy metals and other trace elements. The materials derive from the coal used as fuel and the absorbent used, limestone or quicklime. Depending on the process, the elements leave in different phases. For example, in the wet method, trace elements leave mainly along with the sludge, wastewater, and gypsum formed in the wastewater-treatment plant. A significant portion of boron, bromine, iodine, selenium, and mercury leaves in the gas phase into the atmosphere. In Table 1, the element content of final products and fly ash from the desulfurization methods are in parallel. For example, the heavy-metal and trace-element contents of gypsum are below 10 and usually below 1 mg/kg; an exception is fluoride, which is below 100 mg/kg (R. Meij 1989). Based on these results, the gypsum does not contain these elements in toxic concentrations. According to the Dutch chemical-waste classification, the sludge formed in wastewater treatment would be classified as a chemical waste, because of its selenium and fluoride concentrations. The heavy-metal concentrations of fly ash are clearly higher than those of desulfurization products. If the concentrations are compared with the maximum concentrations give for purification plants used in agriculture (guideline 4/1991 of the Environmental Protection Section of the Ministry of the Environment), there are excesses in the mercury concentration of the sludge and nickel in the second Lifac [product].

Table 1. Elemental concentrations of various desulfurization products and fly ash

	GYPSUM	SLUDGE	LIFAC		SEMI-DRY METHOD		FLY ASH
			I	II	I	II	
Ca%	24	23.9	10.7	13.7	30	26	2.5
S%	17.2	17.5	2.3	2.6	15.1	17.8	–
Si%	0.2	3.74	19.6	13.2	–	0.6	24
Al%	6.14	1.58	11.6	6.7	1.0	0.3	7.4
Fe%	8.37	0.77	5.4	3.4	0.6	0.2	5.3
K%	–	–	1.6	1.2	–	0.08	1.7
Na%	1.34	0.14	4.1	0.6	1.2	1.2	0.8
Mg%	2.14	0.09	1.8	0.7	–	–	1.0
Ti%	0.62	0.1	0.5	0.4	–	–	–
Cl%	<0.50	0.1	0.3	1.1	0.3	2.6	–
F%	0.73	0.67	–	–	–	–	–
As mg/kg	1.9	26	120	–	10	1	21
B mg/kg	< 3	79	–	–	–	–	–
Ba mg/kg	–	–	1100	80	190	< 100	1600
Be mg/kg	< 1	2.7	–	–	–	–	–
Br mg/kg	<0.19	7	–	–	–	–	–
Cd mg/kg	<0.05	0.3	<0.5	0.76	< 5	0.5	< 5
Co mg/kg	–	–	42	–	10	< 4	39
Cr mg/kg	< 3	33	150	77	< 80	< 100	170
Cu mg/kg	0.6	40	–	105	–	–	–
Hg mg/kg	<0.5	6	–	–	–	–	–
Mn mg/kg	< 2	276	420	200	430	100	430
Mo mg/kg	–	–	17	8	30	< 1	30
Ni mg/kg	<0.5	16	< 100	105	< 50	< 100	110
Pb mg/kg	5.7	57	110	56.3	15	< 1	80
Sb mg/kg	0.12	3	7	–	1	< 1	10
Sc mg/kg	0.19	7.3	–	–	–	–	–
Se mg/kg	< 2	111	17	–	4	16	5
V mg/kg	< 10	100	200	202	14	7	140
U mg/kg	<0.3	3.7	8	–	1	1	12
Zn mg/kg	< 10	49	280	138	–	27	–

– not analyzed

Samples:

- o Gypsum and sludge (from wastewater-treatment plant): R. Meij 1989
- o Lifac I: Inkoo power plant, J. Ranta et al. 1990, Lifac II: Inkoo power plant, IVO
- o Semi-dry method I: Södertälje power plant, J. Ranta et al. 1990
  Semi-dry method II: Salmisaari power plant, J. Ranta et al. 1990
- o Fly ash: Salmisaari power plant, J. Ranta et al. 1990

3 TOXICITY AND VARIOUS TEST METHODS IN GENERAL

3.1 Concepts of toxicology

Toxicology is a branch of science that studies substances foreign to living organisms and their effects. By toxicity is meant the substance's own ability to cause damage in the organism even in small dosages.

There are various kinds of poisons. The are divided into acute, delayed, and chronic poisons. In acute poisoning, exposure is brief and the poisonous substance is absorbed rapidly, upon which the symptoms also appear rapidly. In a delayed poison, it takes several days or weeks for symptoms to appear after one or more doses of the poison. Chronic poisoning covers repeated exposures over a long period of time.

A poisonous substance has a local effect if it affects only the place where it comes into contact with the organism, for example, skin, eyes, digestive tract, respiratory tracts. A substance has a general or systemically acting effect when the toxic effect appears elsewhere than the place where the substance first came into contact with the organism.

The reactions caused by a poisonous substance in the system are affected by physical and chemical characteristics such as solubility, vapor pressure, ionization constant, chemical activity, stability, and grain size. Factors connected with the test arrangement (absorption path, dosage, administration rate, solvent, state, etc.), and biological factors, such as absorbance, distribution, metabolism, excretion, animal species, and etc., also affect the organism's reaction.

A toxic substance can travel into organisms through the digestive tract, respiratory tract, skin, eyes, and blood-circulation system.

The toxicity of substances can be evaluated with various limit values. ED_{50} (effective dose 50) means the quantity of the substance (mg, g, mL/kg) that causes a particular effect on half of a group of test animals, on average. The variable studied does not have to be mortality, as is defined for LD_{50} (lethal dose 50), but, for example, vomiting, seizures, and changes in muscle tension can be chosen. Limits causing toxicity can also be expressed as concentrations of substances, in which case EC_{50} and LC_{50} values are used.

3.2 Test method for toxicity of seepage water

The toxicity-testing methods for wastewaters have been applied to toxicity testing of seepage waters obtained from carbon fly ash and desulfurization products.

3.2.1 Various shaking and leachability tests

The leaching behavior of fly ash and desulfurization products is investigated by shaking, column, and lysimetry tests. Seepage waters obtained by these methods are used in various dilutions as test solutions in toxicity tests.

In a shaking test, a certain amount of solid matter is mixed with a certain amount of water in a closed container, which is shaken. The composition of the leach solution (e.g. distilled water, acidified water) and its quantity with respect to solid matter varies according to the shaking test used. After shaking, the mixture is filtered, and the dissolved substances are determined from the filtrate. In Table 2 there is a summary of the best known and most used shaking tests.

Some tests are connected with concentration standards with which the concentrations of harmful substances in the test solution are compared. These guideline values are used, among other things, in classifying problem waste and other waste and in evaluating the suitability of the wastes for landfill. The concentration standards of different countries are not comparable to one another, due to differences among methods and sample handling and test goals and application targets.

The situation of a landfill is described best by a column test, in which the leach solution filtered through the substance being studied and the seepage-water fractions formed are collected and analyzed. In a lysimetry test, the substance being studied is placed in an outdoor vat, in which case weather conditions are taken into account. Water samples can be taken from seepage water at the bottom of the vat, capillary water, and overflow water. Column and lysimetry tests take months, even years; shaking tests take hours or days.

Table 2. Shaking tests of various countries (L. Laitinen 1990)

	GERMANY	UNITED STATES			SWEDEN
	DEV-S4	California	EPA/EP	EPA/TCLP	ENA
Liquid/solid ratio	10:1	10:1	20:1	20:1	1. 4,8,12,16:1 2. 1:1
Leach liquid	Distilled deionized water	Citric acid	Acetic acid	1. Acetic acid + NaOH or 2. Acetic acid	Distilled water
pH	not set	4.5	5	not set (If the pH of the dissolved substance is < 5, leach solution 1 is used, otherwise 2.)	4
Number of leachings	1	4	1	1	1. 1 2. 4
Leaching time	24 h	2, 6, 14, and 30 days	24 h	18 h	24 h
Mixing	not defined	not defined	rate: 40 rpm	rate: 30 rpm	not defined

Effect of the solvent used in the shaking test on toxicity

Various leaching solutions can be used in the shaking tests, for example, ion-exchanged or distilled water, sodium-acetate solution, and water acidified with sulfuric acid. The composition of the leaching solution affects, along with the shaking method and time, the amount of substances leached and thereby the toxicity of the solution. S. A. Peterson et al. (1990) studied the toxicity of leached shaking solutions from municipal and industrial waste with sodium-acetate solution and ion-exchanged water. The shakings were performed following the

TCLP (Toxicity Characteristic Leaching Procedure) shaking test, in which a sodium-acetate solution was used specifically as the leach solution. The toxicity of the leaching solutions alone was also tested. The test species used in the toxicity tests were the green algae *Selenastrum capricornutum,* the water flea *Daphnia magna,* the lettuce *Lactuca sativa,* and the bacterium *Photobacterium phosphoreum.* The sodium-acetate solution, the pH of which was 5.0, was very toxic to all test organisms; for example, an LC_{50} value of 7.6% was obtained for *D. magna,* and an EC_{50} value of 0.5% was obtained for green algae. The tolerance values for pH in the test species are between 6 and 10. Changing the pH to 7.0 (with 0.1N NaOH) reduced the toxicity by about 2.5 times for both the green algae and lettuce, and about 6 times for the water flea. Taken generally, the toxic effects of TCLP leach solutions were much greater on the algae, water flea, and lettuce than those of solutions obtained with seepage water. The increased toxic effect is difficult to explain, since toxicity due to the leach solution itself and toxicity to the test species caused by the substances leached from the waste cannot be separated from each other. The more acidic sodium-acetate solution dissolves certain metals better. According to the study, the use of water as a leach solution would reduce possible positive toxicity results as compared to the TCLP leach solution.

In the EPRI study (I. P. Murarka and D. Friedman 1988), differences in dissolving substances were compared for two shaking tests, EP and TCLP. It was noted in the study that concentrations are generally greater in TCLP shaking than in EP shaking. This is presumed to be due to differences in the leach solutions (acetic acid in EP and either acetic acid or an acetate buffer in TCLP) and to the lack of pH regulation during TCLP shaking. In another study (L. P. Jackson and S. Sorini 1987), in which the results given by these shaking tests were also compared, it was observed that TCLP shaking dissolved larger concentrations of silver, arsenic, and chromium from the same wastes, whereas with the EP test, larges concentrations of barium were obtained. Mentioned advantages of TCLP shaking were better reproducibility, easier performance of the work, and shorter shaking time compared to the EP test (Electric Power Research Inst. 1986).

3.2.2 Toxicity of waters

Poisonous substances appearing in wastewaters rarely cause direct toxicity in humans, but they can cause damage to the human environment. Toxicity is usually due to the combined effect of many compounds, so in addition to chemical analyses, biological testing methods are also to be used in testing wastewaters. Toxicity tests of wastewaters can be divided into lethal and sub-lethal tests.

In lethal tests, the mortality of test organisms is usually proportional to the poison concentration of the wastewaters and to the length of the exposure time. Fish, animal plankton (water fleas), clams, shrimp, etc., can be used as test organisms in lethal tests. In sub-lethal tests, we generally strive to investigate the nature of the toxic effect and to look for the concentration at which toxic effects are not longer observable (safe concentration). Sub-lethal tests are generally done in a laboratory with fish. These tests include biochemical, physiological, histochemical, growth, behavior, activity, and life-cycle testing, as well as studying the danger of taste errors and nutrients. The toxicity of wastewaters can also be studies with algae tests, which are often so-called short-term tests, and bacterial tests (decomposition bacteria).

Ecosystem models have been used in investigating travel through the food chain. Poison enrichment in the food chain can be observed with the aid of chemical analyses. In addition to this, however, we should always also study the biological effects of the observed poison concentrations.

3.2.3 *Daphnia magna* test

With this test (SFS 5062), the acute toxicity of substances in the form of aqueous solutions is studied on the water flea, *Daphnia magna.* The goal of the water-flea test is to determine the EC_{50} (24 h) value of the solution being studied (effective concentration 50%). This is the concentration that makes half of the test animals unable to move within 24 h. If necessary, the concentration that makes half of the test animals unable to move within 48 h, in other words EC_{50} (48 h), can also be determined.

In the tests, a series of dilutions of the aqueous solution to be studied is prepared in test tubes. Water fleas are pipetted along with the last dilution water. The test is performed at the same lighting and temperature (20-22°C) as where the water fleas were raised. Their ability to move is considered to have been lost when they do not move in 15 sec in spite of the test containers being swung carefully. To calculate the EC_{50} values, dilutions are used in which the proportion of moving water fleas is between 10% and 90%. A so-called graphic method can also be used to determine the EC_{50} value.

3.2.4 Rainbow trout test

With this test (SFS 5073), we are able to determine the acute lethal toxicity of a sample being studied on rainbow trout. The result obtained cannot be generalized to other fish species, because

of metabolic differences. This is generally used for a rough characterization of the toxicity of a substance and as a preliminary test for longer-term tests.
In the test, a static or semi-static test arrangement is used. In a static arrangement, the solution being studied is not changed during the test. This method is applied only to samples that are constant over the entire test period. In a semi-static test, some of the solution being studied is replaced daily.
In the test, a dilution series is made in aquariums, in such a way that there is at least 1 L of test solution per kilo of fish. In each dilution there are 10 rainbow trout. With the static method, the 48-hour LC_{50} value is determined for the solution being studied that kills half of the test fish within 48 h. In the semi-static method, the concentration is determined that kills half of the test fish within 96 hours (LC_{50} 96 h).

3.2.5 Toxicity test and with algae-free cultures

Algae have been observed to be sensitive indicators of toxic effects. With this test (SFS 5072), the toxic effect on green algae is measured. A growing one-cell green-algae culture is added to chemical and wastewater dilutions of a nutrient solution or water-system water and to a control solution, the growth or carbon absorption of which is monitored under constant conditions for 3 (4) days. A reduction in the growth or carbon absorption of algae in comparison to the growth of a control culture growing under the same conditions without the wastewater or substance being studied is called inhibition. Growth is measured in volume units of growth in the number of cells and absorption is measured by the binding of radioactive carbon. The result of the algae test is also affected by factors other than actual toxic compounds. The color and particles of the wastewater or substance being studied can slow the growth of algae. On the other hand, nutrients in the wastewater being studied, for example, can increase growth. In this case the ratio of inhibiting and stimulating factors is measured in practice in the test

.

3.2.6 Mutagenicity with the Ames test

By mutagenicity of the substance being studied is meant a change caused by the substance in the hereditary population. The best known short-term test of mutagenicity is the Ames test. In it, strains of the bacterium *Salmonella typhimurium,* which needs histidine as a growth factor, are used as test organisms. In the test, the substance to be studied, a bacteria suspension, and a liver homogenate are pipetted into agar tubes, mixed, and poured into agar cups with a minimum of glucose. The cups are grown for 2 days at +37°C. Then the revertant sites are counted and compared to the controls. A dosage-response curve is drawn from the results, the slope of which

can be used as a measure of mutagenicity. Results from water samples are expressed as the number of mutation sites (revertants/mL of water).
Other microorganisms used in testing mutagenicity include *Escherichia coli* bacteria and *Sacharomyces cervisiae* yeast. A pure microbe test is not sufficient to demonstrate gene toxicity of chemicals, but several different in vivo and in vitro tests have been developed for this purpose with mammals and isolated mammalian cells.

3.3 Other methods used in testing the toxicity of wastes

Evaluating the soil effects of organic and inorganic substances contained in wastewater with earthworms

The fauna in soil are varied, which makes it difficult to evaluate the effects of wastes on the ecosystem of the soil. The earthworm (*Eisenia fetida*) is very common in soil, and it is easy to grow large numbers of them. For this reason, it has been used in evaluating the biological effects of wastes on soil. There are two test forms: the contact test and the artificial-soil test. The contact test lasts 48 h, and in it, we use adult worms, a small glass dish, and filter paper, onto which the chemical or waste to be tested is placed. The purpose of the test is to achieve close contact between the worms and the chemical, as in soil. With this method, the relative toxicity of the chemical or waste can be evaluated rapidly on the basis of skin absorption.
In another test method, a mixture of sand, kaolin, peat, and calcium carbonate is used as an artificial soil. The test material in various concentrations and adult earth worms are added to this mixture, and the survival of the worms is evaluated after two weeks. In this, exposure occurs through skin absorption and food digestion.
On the basis of these studies, the following can be noted:

- earthworms can be used to classify different chemicals with great precision,
- with the earthworm test, the biological effects on soil of chemicals contained in wastes can be evaluated,
- earthworms can be used to classify the effects of chemical groups and certain chemicals,
- with these tests, a relative toxicity for the chemicals can be obtained that is comparable to that of rat tests.

(E. F. Neuhauser et al. 1986)

4 LEACHABILITY OF DESULFURIZATION PRODUCTS AND FLY ASH

Environmental damage from desulfurization products and fly ash derives from substances leached from them that are spread along with rainwater into the environment of the storage site, especially into surface and groundwaters. Dissolved concentrations can have especially harmful effects on the environment. Damage caused to humans derives mainly from the danger of polluted groundwaters. The size and number of injuries depend on both the leached substances and special features of the storage site and its environment.

In estimating the environmental effects that may be caused by fly ash and desulfurization products, the following are to be taken into account:

- substances that are leached from the waste and their concentrations in seepage water,
- quantity of seepage waters,
- transport paths of seepage waters,
- possible binding of harmful substances contained in seepage waters to soil or rock,
- dilution of seepage waters in surface and groundwaters,
- locations of water intakes,
- largest permitted concentrations in drinking water, and
- tolerance of the environment.

Many different leachability tests have been conducted for desulfurization products and fly ash, about which much information is found in the literature. There is not much researched information on the effects of leached substances on the environment. Because desulfurization products are fairly new, no longer-term experience exists with placing them in the ground.

The amount of substances leached into water depends, among other things, on the structure of the fly ash and desulfurization product and the chemical bonds contained in them and the chemical environment of the leaching event. In general, loosely bound compounds such as oxides, carbonates, halides, and sulfates probably dissolve from the surface at the beginning of leaching, along with metals and trace elements bound to them. Leaching then continues with the break-down and decomposition of the more resistant phases. The pH of the water is one of the most important factors affecting leaching: leaching increases as acidity increases. As the particle size of ash goes down, in which case the free surface of the particles increases, leaching also increases (E. Panula-Nikkilä and M. Äijälä 1986: from various sources).
For example, in Denmark, the quality of seepage waters from waste has been investigated by the semi-dry method and substances leaching from gypsum have been investigated by both the

column and lysimetry methods and the wet method. With the same L/S (liquid/solid) ratios, the results obtained varied between the column and lysimetry methods, which is presumed to be due to pozzolana hardening reactions. In long-term lysimetry tests, the sample has time to harden, whereas in column tests, seepage events lasting up to thousands of years are simulated in a few months, in which case the pozzolana reaction does not have time to occur. Higher concentrations were indeed measured in seepage waters in column tests than from seepage waters in lysimetry tests. In Table 3, there are estimates of the quality of the first seepage waters formed at the storage site (J. Ranta et al. 1987, Hjelmar 1985).

Table 3, Substances leached from desulfurization products and fly ash and their concentrations

CONCENTRATION RANGE, mg/L	GYPSUM FROM, WET METHOD, L/S 0.00-0.1 (column test)	PRODUCT FROM SEMI-DRY METHOD, L/S 0.08-0.12 (lysimetry test)	COAL FLY ASH, L/S 0.03-0.07 (lysimetry test)
≥ 100	SO_4^{2-}, Cl^-, Na, Ca, Mg	SO_4^{2-}, Cl^-, Na, K, NO_3^- + NO_2^-	SO_4^{2-}, Cl^-, Na, K
10-100	K	Ca, Cr, Mo, V	Cr, Mo
1-10	NO_3^- + NO_2^-, F^-	NH_4^+, Mg	B, Ca, V
0.1-1	NH_4^+, B, Zn	F, B, Ba	NH_4^+, NO_3^- + NO_2^-, PO_4^{3-}, F^-, Mg, As, Ba, Se
0.001-0.1	PO_4^{3-}, Ba, Cr, Mo, Se, V	As, Ni, Se, Zn	
0.001-0.01	A, Cd, Cu, Ni, Pb	PO_4^{3-}, Cu	
<0.001	Hg	Cd, Co, Hg, Pb	Hg, Cd

In these estimates, the largest concentrations were of sulfates, calcium, chlorides, sodium and potassium. Of the substances harmful to the environment, such as arsenic, chromium, selenium, and molybdenum, the concentrations were small in the first seepage waters, and no significant amounts of other heavy metals were found. The concentrations of harmful metals were smaller in seepage waters from desulfurization products, especially gypsum, than in seepage waters from fly ash. Also in shaking tests (Kol-Hälsa-Miljö project 1983), larger concentrations were found for fly ash than for desulfurization products.

Hjelmar has estimated the average compositions of desulfurization products during the first hundred years from when seepage waters start to form at the storage site (Table 4). In these, the seepage-water product from the semi-dry method contains larger concentrations of arsenic, chromium, molybdenum, and vanadium, etc., than seepage waters from desulfurization gypsum, which is due to the different total amounts of the substances in question in the products.

Table 4. Estimated quality of seepage waters during the first hundred years of formation of seepage waters (O. Hjelmar)

mg/L	Product from semi-dry method (contains about 60% fly ash)	Desulfurization gypsum from dry method
pH	12*	7
Solid-matter content	7000	3300
Alkalinity, meq/L	50*	0.8
Sulfate	2600	1700
Fluoride	1.7	9
Chloride	280	350
Total nitrogen	280	1.5
Boron	0.4	0.2
Sodium	1800*	180
Potassium	190	18
Calcium	820*	640
Magnesium	150*	90
Arsenic	0.01	0.0009
Barium	0.36	0.06
Cadmium	0.00007	0.006
Chromium	8	0.01
Copper	0.06	0.005
Mercury	<0.0001	<0.0001
Molybdenum	7	0.05
Nickel	0.007	0.002
Lead	<0.005	0.0007
Selenium	0.08	0.01
Vanadium	6	0.1
Zinc	0.006	0.07

* value uncertain

4.1 Comparison of results of leachability tests

The results obtained form the leachability tests can be compared, for example, with corresponding concentrations from pure natural waters or with concentrations of surface and groundwaters at the storage site. Limit values for household water are also used for comparison. In comparing these values, it is to be noted that seepage water from wastes was not intended to be used

Table 5. Quality requirements for household water and landfill-suitability criteria in different countries

mg/L	Household water, FINLAND	Household water, GERMANY	GERMANY landfill-suitability criteria for wastes				USA EPA/ EP and TCLP	SWITZERLAND, landfill classification		Limits for water fauna
			lf 1	lf 2	lf 3	spec. lf		lf 1	lf 2	
pH	6.5-8.8	6.5-9.5 ± 0.1	5.5-10	5.5-12	5.5-12	4-13	–	6-11	6-11	6.5-8
conductivity (mS/m)	–	–	< 100	< 300	–	10^4	–	–	–	150
COD_{Cr} (mg O_2/L)	3.0* (Mn)	–	20	50	–	–	–	–	–	10
permanganate number, $KMNO_4$	12*	–	–	–	–	–	–	–	–	-
Water-soluble portion	–	–	–	–	–	10%	–	0.5%	5%	–
aluminum	0.2*	0.2	–	–	–	–	–	1.0	10	–
ammonia (mg N/L)	–	–	0.08	4.1	–	–	–	0.5	5	–
ammonium	0.5*	0.5	–	–	–	1000	–	–	–	0.02
antimony	–	–	0.05	0.1	1.0	–	–	–	–	–
arsenic	0.05	0.04	0.05	0.1	1.0	–	5.0	0.01	0.1	0.05

barium	–	–	1.0	1.0	5.0	–	100	0.5	5.0	0.001
beryllium	–	–	0.004	0.005	0.05	–	–	–	–	–
boron	–	–	1.0	1.0	10.0	–	–	–	–	–
mercury	0.001	0.001	0.001	0.005	0.05	0.1	0.2	0.005	0.01	10^{-4}
fluoride	1.5	1.5	1.5	5.0	20.0	50	–	1.0	10	–
phosphate	0.1 (P)*	–	1.6	3.3	–	–	–	1	10	0.1 (P)
silver	–	–	0.01	0.1	0.5	–	5.0	0.01	0.1	0.01
cadmium	0.005	0.005	0.005	0.05	0.5	0.5	1.0	0.01	0.1	0.2
chloride	100*	–	200	350	–	6000	–	–	–	–
mg/L	Household water, FINLAND	Household water, GERMANY	GERMANY landfill-suitability criteria for wastes				USA EPA/ EP and TCLP	SWITZERLAND, landfill classification		Limits for water fauna
			lf 1	lf 2	lf 3	spec. lf		lf 1	lf 2	
cobalt	–	–	0.05	0.5	2.0	–	–	0.05	0.5	–
chromium (total)	0.05	0.05	0.05	1.0	10.0	0.5 VI	5.0 VI	0.01 VI	0.1 VI	0.04
copper	0.3*	–	0.1	1.0	10.0	10	–	0.2	0.5	0.005
lead	0.05	0.04	0.05	0.5	2.0	2.0	5.0	0.1	1	0.03
manganese	0.1*	0.05	0.5	1.0	–	–	–	–	–	0.2
molybdenum	–	–	–	–	–	–	–	–	–	–

sodium	150*	–	–	–	–	–	–	–	–	–
nickel	0.05	0.05	0.05	0.5	10.0	2.0	–	0.2	2.0	0.025
nitrate	25	50	11.3	22.6	--	–	--	–	–	5
nitrite	0.1	–	0.15	0.3	–	30	–	0.1	1.0	1
iron	0.2*	0.2	1.0	2.0	–	–	–	–	–	0.3
zinc	3.0*	20	0.1	5.0	10.0	10	–	0.5	5.0	0.03
selenium	0.01	–	0.01	0.05	0.5	–	1.0	–	–	0.005
sulfate	100*	240	250	500	–	5000	–	–	–	–
sulfide	–	–	–	–	–	–	–	0.01	0.1	0.02
sulfite	–	–	–	–	–	–	–	0.1	1.0	–
cyanide (total)	0.05	0.05	0.05	0.5	20.0	1 vap.	–	0.01 vap.	0.1 vap.	0.005
thallium	–	–	0.01	0.1	2.0	–	–	–	–	–
tin	–	–	0.5	0.5	10.0	–	–	0.2	2.0	–
vanadium	--	–	0.05	0.2	2.0	–	–	–	–	–
carbon tetrachloride, CCl_4	0.003	–	–	–	–	0.07	–	–	–	–
chlorophenols	0.01	–	–	–	–	–	–	–	–	0.001
pesticides	WHO	–	–	–	–	–	–	0.005	0.005	–

	guidelines									
mineral oils	0.05*	–	–	–	–	–	–	–	–	–
quantity of organic carbon, TOC	3.5*	–	–	–	–	200	–	20	50	-

* quality goals

– limit value not defined

Sources:

- o Household water, Finland (General letter No. 1977, Drug Administration, 1991)
- o Household water, Germany
- o Landfill-suitability criteria for wastes, Germany (D. von Fischer and W. Schenkel 1990); according to DEV-S4 shaking
- o USA EPA/EP and TCLP (L. Laitinen 1990)
- o Switzerland landfill-suitability criteria (D. von Fischer and W. Schenkel 1990: lf 1, landfill for inert wastes, lf 2 landfill for residual materials. Shaking solution: carbonated water, 2 x 24 h, average of solution concentrations (24, 48 h)
- o Concentrations of substances contained in water favorable to water fauna: Environment Canada. 1980. References to the quality of waters. Guide to water-quality parameters. Environment Canada. General Department of Interior Waters, Ottawa.

as household water. In some countries, concentration standards and guidelines connected with shaking tests for wastes have been given. The values of different countries are not comparable to one another, because, among other reasons, test methods and sample handling differ among themselves. Landfill-suitability guidelines have also been used according to the danger of the wastes. In Table 5, quality requirements in Finland and German given for household water and limit values used in various countries in interpreting the results of shaking tests have been collected. In addition, guidelines given in Canada to protect water fauna are there.

4.2 Results of leachability tests

4.2.1 Desulfurization products

In a German study (H. J. Einbrodt and D. Prajsnar 1988), substances leaching from natural gypsum and desulfurization gypsum were studied. Solubility tests were performed at 40°C from dried samples according to the German shaking test (DEV-S4). In it, 100-g samples were mixed into a liter of ion-exchanged water and shaken for 24 h. In another shaking test, water acidified with carbonic acid was used as the leaching solution (pH 4.1-4.5). The results are in Table 6. The solubility of the samples varied between 2.2 and 2.4%. Differences between natural and desulfurization gypsum are in the quantity of dissolved fluoride, which exceeds the limits given for household water in shaking tests of desulfurization gypsum. Quantities of soluble sulfate are large in both samples, which, according to the German classification, would lead to the gypsum being placed in a special landfill (limit: < 5000 mg/L). Concentrations of heavy metals were small and stayed below the limit values. Mercury quantities were near the limits in this study, however. Manganese concentrations also exceeded the limits clearly, but this was not considered dangerous in the study, because manganese is important for humans as an enzyme activator. Based on the study, it can be noted that leachable substances from natural gypsum and desulfurization gypsum do not cause damage to soil and drinking water according to present knowledge, and thus they are not harmful to humans.

Table 6. Concentrations of substances leachable from natural gypsum and desulfurization gypsum compared to household-water standards (H. J. Einbrodt and D. Prajsnar, 1988)

	NATURAL GYPSUM mg/L		DESULFURIZATION GYPSUM mg/L		HOUSEHOLD-WATER STANDARDS, mg/L	
	Average	Range	Average	Range	FINLAND	GERMANY
pH	6.61	< 6 – 7.62	6.63	< 6 – 7.51	6.5-8.8	6.5-9.5 ± 0.1
SO_4^{2-}	1466	1362 – 1534	1411	1351 – 1470	100*	240
CN^-	0.01	n.n. – 0.06	0.01	n.n. – 0.08	0.05	0.05
F^-	2.7	0.2 – 5.0	6.3	0.5 – 11.0	1.5	1.5
NO_3^-	5.5	< 5.0 – 12.0	3.7	0.3 – 13.6	25	50
PO_4^{3-}	0.15	<0.15 – 0.21	<0.15	<0.15 – 0.18	0.1 (P)*	–
Cl^-	3.6	< 2.0 – 22.6	9.3	n.n. – 20.0	100*	–
NH_4^+	0.6	<0.1 – 5.5	0.3	0.1 – 0.6	0.5*	0.5
Al	0.002	–	0.12	–	0.2*	0.2
Fe	0.001	–	0.001	–	0.2*	0.2
K	–	0.11 – 0.30	–		–	12
Mg	0.004	–	0.007	0.77 – 1.23	–	50
Mn	0.01	–	–	0.40 – 0.82	0.1*	0.05
Na	–	1.24 – 2.25	–	1.24 – 2.25	150*	150
Pb	–	n.n. – 0.002	0.006	n.n. – 0.019	0.05	0.04
Cd	–	n.n. – <0.001	0.002	n.n. – 0.006	0.005	0.005
Ni	–	n.n. – <0.001	0.018	0.001 – 0.058	0.05	0.05
Cr	–	<0.001 – 0.005	0.005	0.001 – 0.013	0.05	0.05
Zn	–	0.043 – 0.130	0.290	0.037 – 0.692	3.0*	20
Hg	–	<0.001	0.001	n.n. – 0.002	0.001	0.001
As	–	n.n.	0.001	0.001 – 0.002	0.05	0.04

* recommendations
– result not reported/Limit value not defined
n.n. below limits of determination

In Table 7, results of leaching tests of desulfurization products taken from the literature have been collected.

In Sweden, the product from the semi-dry desulfurization method (A1, A2 in the table) and a stabilized product (A3, A4) have been studied. The solution obtained as a result of shakings was alkaline. Chloride concentrations were high in solutions of desulfurization products, and they even exceeded the limit value (100 mg/L) set for household water by four thousand times. Chloride appears in the product as easily soluble calcium chloride.
The chloride quantities that leached from a mixture of fly ash and desulfurization product (A3, A4) were significantly smaller. The concentrations of soluble sulfate were small from the semi-dry desulfurization product compared, for example, to the concentrations in cement and fly ash (3000 and 1000 mg/L). Heavy-metal concentrations were low, instead.

The effect of stabilization on the leachability of substances appears good from the product of the semi-dry method (B1, B2) in the EP shaking test performed (E. Jøns 1984: EPRI). Trace-element concentrations were 5-10 times smaller in the stabilized product than in the plain desulfurization product. Concentrations are small, in general.

Table 7. Results of desulfurization leachability tests collected from the literature

mg/L	product from semi-dry method				product from semi-dry method		Product from dry method, C
	A1	A2	A3	A4	B1	B2	
pH	–	–	–	–	–	–	12.5
aluminum	–	–	–	–	1.3	<0.05	–
antimony	–	–	–	–	<0.2	<0.03	–
arsenic	0.057	<0.15	<0.030	<0.15	<0.003	<0.003	<0.001
barium	1.1	1.6	0.19	0.75	0.93	0.47	2.4
beryllium	0.001	<0.01	<0.001	<0.01	<0.003	<0.0005	–
boron	–	–	–	–	1.4	0.82	4.2
mercury	–	–	–	–	0.0017	0.0003	<0.0002
fluoride	–	–	–	–	–	–	1.4
phosphate	260 (P)	44 (P)	0.8 (P)	1.7 (P)	–	–	–
silver	–	–	–	–	<0.01	<0.002	<0.0005
cadmium	0.010	<0.03	<0.005	<0.03	<0.0005	<0.0005	<0.0002
chloride	12800	36900	440	385	–	–	49.9

mg/L	product from semi-dry method				product from semi-dry method		Product from dry method, C
	A1	A2	A3	A4	B1	B2	
cobalt	0.009	<0.02	<0.003	0.03	<0.03	<0.006	–
chromium	0.073	<0.04	0.10	0.25	<0.005	<0.011	0.1
copper	0.78	<0.03	0.16	<0.03	0.019	<0.001	<0.1
lead	0.12	1.8	<0.050	1.8	<0.002	<0.002	–
manganese	0.002	0.013	0.003	0.02	4.1	0.09	–
molybdenum	0.025	0.02	1.3	0.28	0.52	0.056	–
nickel	<0.002	0.10	<0.02	<0.10	0.10	0.006	–
nitrate	–	–	–	–	–	–	0.1-6 (N)
nitrite	–	–	–	–	–	–	0.004 (N)
iron	0.17	5.7	0.04	0.045	0.084	0.019	<0.1
zinc	0.01	<0.01	0.04	<0.01	<0.02	<0.003	–
selenium	–	–	–	–	0.01	<0.003	0.012
sulfate	430	168	1260	312	–	–	1250
cyanide	–	–	–	–	–	–	<0.02
thallium	–	–	–	–	<0.4	<0.09	–
tin	–	–	–	–	<0.6	<0.1	–
vanadium	–	0.09	–	0.12	0.70	0.12	–
calcium	7300	9900	1360	1034	2300	110	–
potassium	540	503	70	89	9.5	2.3	–
lithium	0.20	0.19	1.2	2.3	–	–	–
magnesium	0.46	1015	0.16	0.83	0.002	3.2	–
sodium	60	68	52	71	17	10	–
strontium	9.3	16	3.5	3.8	16	1.5	–
titanium	–	–	–	–	<0.02	<0.005	–

– not determined/not reported

Sources:

o A J. Hartien, et al. 1986: Maximum concentrations, shaking test.
Final products 1 and 2 from semi-dry method, Södertälje.

Stabilized final products 3 (80% FGD/20% FA) and 4 (70% FGD/30% FA), Niro Copenhagen.

o B E. Jøns 1984: EP shaking test (EPRI). Final product from semi-dry method. 1 not stabilized, 2 stabilized.

o C Z. Zhou and R. Dayal 1990: water as shaking solution, L/S 10. Product from dry method (LIF), Ontario.

Zhou and Daval have studied the product of the dry desulfurization method (C) with a leachability test that corresponds to the German DEV-S4 shaking test when the leaching solution was water. These values were compared to the Canadian limit values for dangerous wastes (for example, As <5 mg/L, Cd <0.5 mg/L, Cr <0.5 mg/L), which they were clearly below. The product can thus be considered not dangerous within the framework of these criteria.

The VTT [Technical Research Center of Finland] has studied substances leachable from the desulfurization product of the semi-dry method with column and shaking tests (J. Ranta et al. 1990). The samples were from the Salmisaari power plant and from Södertälje. Leachability tests were make with a mixture of the product from the semi-dry method and fly ash (ratios 65:35 and 50:50). The pH of the seepage waters varied between 10 and 12.5, and the main components were calcium, sulfate, chloride, and nitrite/nitrate. Their concentrations clearly exceeded the limit values permitted for household water, for example. The concentrations of harmful metals were small, generally below 1 mg/L and below the household-water standards, except for chromium in a few sample solutions. More chromium and molybdenum also leached from the desulfurization product than from the usual construction materials used as comparison materials. Leaching of metals decreased clearly over time as the material hardened.

In a broad American study of solid wastes, the leachability of solid wastes arising from fluidized-bed combustion and desulfurization (G. M. Kaszynski and S. T. Helm 1987) was studied. On the basis of the results of numerous leachability tests (including EP), no large amounts of harmful substances leached from the samples, and the concentrations were below the limits of the RCRA (Resource Conservation and Recovery Act). RCRA has given limit values for either heavy metals (As, Ba, Cd, Cr, Pb, Hg, Se, and Ag) that are 100 times the concentration of the drinking-water standard. Also according to another study (R. D. Achord et al. 1990), ashes arising from fluidized-bed combustion and desulfurization can be classified as not dangerous. In it, leachability of the samples was studied with the EP, TCLP, and ASTM shaking tests.

In the chemistry laboratory of Imatra Power, substances that leach from gypsum from the wet method were also studied with shaking tests. The samples were obtained from the Netherlands and Denmark. Shakings were done on the Dutch sample according to the ENA test. From the Danish sample, the maximum concentrations were determined with the ENA test (L/S 1:1). Shaking was done on both according to the German DEV-S4 shaking test (L/S 10:1, 1x24 h). In all shakings, water acidified with carbon dioxide (pH about 4) was used as the leach solution. The results of the shakings are in Table 8.

Table 8. Results of shakings of gypsum from the wet method (IVO)

mg/L	Gypsum from the wet method (Dutch) L/S 1:1	4:1	8:1	12:1	16:1	10:1	(Danish) L/S 1:1	10:1
pH	7.7	6.2	6.0	5.8	5.6	6	7.3	6.9
conductivity (mS/m)	276	243	236	236	232	263	320	250
aluminum	1.02	9.82	17.9	7.97	5.47	8.2	0.413	0.100
ammonium	0.07	0.37	0.45	0.47	0.43	0.30	0.14	0.28
arsenic	<0.005	–	–	–	–	<0.005	<0.005	<0.005
barium	0.051	0.073	0.074	0.063	0.049	<0.7	<0.5	<0.5
mercury	<0.0001	–	–	–	–	<0.0001	0.0005	0.0001
fluoride	7.4	–	–	–	–	12.5	5.1	4.8
phosphate	0.016	0.037	0.046	0.05	0.019	<0.1	0.02	0.06
cadmium	<0.0001	<0.0001	0.0003	0.0001	0.0002	<0.0003	<0.0003	0.0015
chloride	47.6	10.9	0.63	0.29	0.41	10.0	335	23
chromium	0.015	0.017	0.019	0.019	0.008	0.006	0.002	<0.001
copper	0.005	0.009	0.013	0.021	0.024	0.008	0.037	0.031
lead	0.001	0.001	0.002	0.002	0.001	<0.005	<0.005	<0.005
manganese	0.87	0.80	0.43	0.31	0.15	0.37	0.23	0.19

molybdenum	0.0037	0.0013	0.0008	0.0006	<0.0005	<0.003	0.006	0.003
nickel	<0.10	<0.10	0.10	<0.10	<0.10	0.006	0.010	<0.005
nitrate	0.11	0.03	<0.001	<0.001	<0.001	0.15	2.9	0.13
nitrite	0.009	0.007	0.006	0.008	0.002	<0.1	0.03	0.05
iron	0.88	2.22	2.66	2.86	0.92	1.99	0.23	0.027
zinc	0.023	0.107	0.076	0.047	0.032	0.18	0.08	0.10
sulfate	1490	1540	1600	1560	1690	1550	1406	1395
vanadium	0.020	0.020	0.018	0.024	0.011	<0.02	<0.02	<0.02
bromine	0.26	<0.1	<0.1	<0.1	<0.1	<0.1	2.6	<0.1
total calcium	699	699	681	666	644	755	730	665
potassium	6.29	3.83	2.75	1.85	0.92	2.9	4.00	0.49
magnesium	24	7.25	1.68	0.71	0.34	5.1	20.7	2.35
sodium	38.1	9.62	1.57	0.55	0.35	8.6	18.8	1.54
total phosphorus	0.02	0.04	0.05	0.06	0.02	0.034	0.12	0.02

In evaluating the results of the shakings, the limit values given for household water can be used, for example, as comparison values. For the Danish gypsum, the concentrations exceeded the household-water limits clearly in the 1:1 shaking for chloride (limit 100 mg/L), sulfate (limit 100 mg/L), and fluoride (limit 1.5 mg/L), and slightly for manganese, total phosphorus, and iron. In the second 10:1 shaking, there were excessive concentrations of fluoride, sulfate, and manganese. In evaluating the landfill classification in use in Germany and the results based on its concentration limits, the gypsum would be classified in the lowest landfill class. Values for fluoride and conductivity are in the second landfill class, and the sulfate concentration is in the special landfill class. In the shaking tests on the Dutch gypsum, for aluminum, manganese, iron, and sulfate concentrations are clearly excessive. The quantities of leached chloride are clearly lower than those of the Danish gypsum, for example. The heavy-metal concentrations are clearly even below those of the household-water standards.

4.2.2 Sludge arising in the purification of wastewaters

In the wet method, the quality of the gypsum formed is important. In order obtained gypsum that is as pure as possible, gypsum and water into which chlorides and other soluble impurities have leached are removed from the wash-sludge cycle. This mixture goes through a purification: neutralization, flocking, precipitation, sedimentation, and water removal. The solid product formed in the purification consists mainly of calcium sulfate, calcium fluoride, and silicon, aluminum, iron, and magnesium compounds. In Table 9, composition information has been collected from two different sources, and concentrations of the so-called filter cake studied at IVO have been added. The range of heavy-metal concentrations of the samples from sources 1 and 2 is quite large, and concentrations in the upper values can cause them to be classified as problem wastes. The values from source 1 were compared to the limit values given for agricultural land in Germany, which they were always below, however. In Germany, for example, about 115,000 tons of this kind of sludge was formed in the year 1989, of which 55% was used as a cement additive and filler material Recycling Plan for Residues from Coal Power Plants, Part III: Residues from Water and Wastewater Treatment. Vol. 70, 12/90, pp. 1033-1041. (Verwertungskonzept für Reststoffe aus Kohlekraftwerken, Teil III: Rückstände aus der Wasser- und Abwasseraufbereitung).

The concentrations of wastewater sludge determined at IVO are placed in Table 9 next to the values from the sources. Exceptions, however, are the significantly higher concentrations of arsenic, cadmium, nickel, and lead. If the heavy-metal concentrations obtained are compared with the limit values proposed for purification-plant sludge in Finland, the concentrations were exceeded for many substances. For example, cadmium, lead, and mercury concentrations are about ten times and those of nickel and zinc 2-3 times the limit values. The concentration of chromium was the only one that stayed clearly below the proposed limits. The sludge that was studied would not be suitable for spreading onto agricultural land within the framework of these limits. The so-called filter cake obtained for study was derived from Germany.

Shaking tests were also made on a sample received from IVO, the results of which are in Table 10. The concentrations measured from the shaking solutions are high for chloride, nitrate, calcium, and sodium, for example. The leachability of trace elements, such as lead, arsenic, manganese, and zinc is surprisingly small compared to concentrations of these substances in the solid product. This is probably due to saturation of the solution and the general low solubility of trace elements. Of the trace elements, lead, zinc, selenium, copper, and chromium had concentrations clearly below the Finnish household-water standards. Concentrations clearly above the limit values were obtained for arsenic, mercury, fluoride, cadmium, and nickel. According to the German landfill classification, the so-called filter cake would be special landfill waste based on the chloride and sulfate concentrations, in landfill class 3 for mercury and fluoride, and in landfill class 2 based on the arsenic, cadmium, nickel, and vanadium concentrations. The concentrations of other substances are in landfill class 1 or below it.

Table 9. Composition of sludge from the wastewater-purification plant of a desulfurization plant

	Unit	Source 1	Source 2	Analyzed at IVO
Solid-matter concentration, 105°C	%	25 -35	–	–
Evaporation loss, 1000°C	%	19-32	–	–
SiO_2	%	11-32	0.5-55	22.5
Fe_2O_3	%	2-5	0.5-7	5.43
Al_2O_3	%	6-12	0.1-16	13.0
CaO	%	13-15	30-50	16.6
MgO	%	3-24	1-35	5.86
Na_2O	%	≤1	1-10	0.76
TiO_2	%	–	–	0.83
K_2O	%	≤1	1-10	2.09
SO_3	%	7-10	–	not detected
SO_4	mg/kg	–	25-45	total S, 5.48%
CO_3	%	–	–	1.75
Cl	%	2-4	0.5-8	2.14
F	%	1-4	0.1-10	0.007
total P, P_2O_5	%	–	–	<0.05
As	mg/kg	20	1-240	1570
Ba	mg/kg	300	–	<300
Cd	mg/kg	3-5	2-15	39.0
Cr	mg/kg	100	3-210	190
Ni	mg/kg	100	20-110	290
Pb	mg/kg	40-60	2-360	1854
Hg	mg/kg	5-10	5-70	30
Se	mg/kg	50-150	–	–
Sr	mg/kg	80-400	–	–
Zn	mg/kg	200-300	50-4000	2730
Cu	mg/kg	–	1-305	681
Mn	mg/kg	–	–	3092
Mo	mg/kg	–	–	136
V	mg/kg	–	–	460

– not analyzed

Source 1: F. von Burgmann 1986

Source 2: Verwertungskonzept für Reststoffe aus Kohlekraftwerken, Teil III: Rückstände aus der Wasser- und Abwasseraufbereitung

Table 10. Results of shaking tests on sludge formed in the purification of wastewaters

mg/L	Results of shakings of so-called filter cake L/S 1:1	4:1	8:1	12:1	16:1	10:1
pH	8.8	8.4	8.4	8.2	8.3	8.2
conductivity (mS/ml)	3150	1120	538	372	330	692
aluminum	1.53	0.66	0.92	0.50	0.42	–
ammonium	43	15.5	4.0	1.6	1.2	–
arsenic	0.075	0.066	0.130	0.096	0.094	–
barium	2.35	0.83	<0.5	<0.5	<0.5	–
mercury	0.0265	0.0260	0.0233	0.0122	0.0064	–
fluoride	7.3	10	15	13	12	–
phosphate	0.30	0.02	0.13	0.02	0.01	–
cadmium	0.063	0.027	0.016	0.015	0.014	–
chloride	12200	3210	602	92	15	–
chromium	0.005	0.004	0.004	0.004	0.005	–
copper	0.12	0.15	0.059	0.052	0.045	–
lead	0.07	0.03	0.04	0.02	0.02	–
manganese	0.16	0.42	0.51	0.49	0.54	–
molybdenum	1.9	1.2	1.1	0.7	0.5	–
nickel	0.44	0.47	0.27	0.37	0.32	–
nitrate	1230	395	121	35	8.6	–
nitrite	0.77	0.01	0.03	0.25	0.23	–
iron	0.34	0.13	0.41	0.21	0.18	–
zinc	0.1	0.05	0.05	0.04	<0.03	–
selenium	0.008	0.004	0.003	0.003	0.003	
sulfate	840	1426	2374	2620	1990	–
vanadium	0.16	0.13	0.12	0.11	0.11	–
bromine	78	21	4.2	0.61	0.11	–
total calcium	5810	811	672	593	580	–
potassium	104	31.3	9.10	4.38	2.67	–
magnesium	344	509	417	281	226	–
sodium	332	88.0	14.5	3.68	1.38	
total phosphorus	0.1	0.05	0.13	0.05	0.07	–

– not analyzed

4.2.3 Fly ash

It is not possible to evaluate possible toxicity of fly ash to the water ecosystem by just analyzing the chemical composition. Most fly ash consists mainly of aluminum-silicate glass balls that are only slightly soluble in water. There may be bound substances on these particles, however, which are soluble in water and which can have toxic effects. It is possible to estimate possible contamination of ground and water by making solubility tests.

In Table 11 there are percentages of soluble substances for various fly ashes. In the studies (H. A. van der Sloot et al. 1984), it was noted that there is a dependency between solubility behavior and ash alkalinity when the ratio $(CaO + MgO)/(SO_3 + 0.04Al_2O_3)$ is used to define alkalinity. At a high L/S ratio, all possible substances dissolve from the ash particles, but at smaller ratios, solubility is determined by the pH of the solution, which depends in turn on the ash itself. Finnish fly ash is generally alkaline.

Table 11. Solubility percentages (L/S ratio: 5) for various fly ashes

%	Acidic fly ash	Neutral fly ash	Alkaline fly ash
aluminum	0.001-0.1	0.001-0.1	0.001
antimony	5-10	0.02-5	0.02
arsenic	1-5	0.1-2	0.1
boron	30	1-30	1
cadmium	0.1-20	0.01-0.05	0.05
calcium	10-15	5-15	10-15
chromium	0.05	0.05-1	1
copper	0.01-10	0.005-0.01	0.01
lead	0.005-0.5	0.005-0.1	0.01
magnesium	1-2	0.001-2	0.001
molybdenum	10-100	70-100	70-100
silicon	0.01	0.005-0.01	0.005
zinc	0.01-5	0.005-0.1	0.01
scandium	10-50	0.5-50	0.5
sulfate	50-100	50-100	50-100
uranium	0.05	0.;01-0.05	0.02
vanadium	0.5	0.005-0.5	0.005
tungsten	20	1-20	1

Acidic fly ash R = 0-1.25
Neutral fly ash R = 1.25-2.25
Alkaline fly ash R > 2.25
$R = (CaO + MgO)/(SO_3 + 0.04Al_2O_3)$

Trace elements are generally attached by chemical bonds to the matrix structure of the "bulk phases" of the ash. The most important of these phases are the amorphous, mullite, magnetic, and coal phases. For example, mullite does not dissolve in acid or base, so any metals it contains do not dissolve easily. Metals dangerous to the environment derive from surface layers of particles or from non-mullite phases, which are formed at low burning temperatures. Quartz is also a very inert material, so metals attached to it are practically insoluble. (E. Panula-Nikkilä and M. Äijälä 1986: from various sources)

In Table 12, results from solubility tests of fly ash have been collected from the literature. In Hartien's shakings, in which maximum concentrations were sought, the concentrations are higher than in the other two, in which the L/S ratio was 10. Concentrations were excessive in these shakings for chrome, boron, selenium, sulfate, and cyanide, etc., which would cause them to be placed in a special landfill according to the German landfill classification.

Table 12. Results of solubility tests on fly ash collected from the literature

mg/L	A, L/S 1:1	B, L/S 10:1	C, L/S 10:1
pH	–	–	11-12
arsenic	0.07	0.070	0.03-0.04
barium	0.38	<0.1	0.5-0.9
beryllium	<0.001	–	–
boron	–	–	4.9-9.6
mercury	–	<0.001	–
phosphate	1.5 (P)	–	–
silver	–	<0.001	<0.0001
cadmium	<0.005	0.0001	–
chloride	21	<0.01	4-16
cobalt	<0.003	–	–
chromium	0.36	0.138	0.14-0.22
copper	0.16	<0.01	<0.0001
lead	<0.05	0.0056	–
manganese	0.002	0.00075	–

mg/L	A, L/S 1:1	B, L/S 10:1	C, L/S 10:1
molybdenum	2.2	–	–
nickel	<0.02	–	–
nitrate	–	–	0.01-0.34 (N)
iron	0.08	0.060	<0.05
zinc	0.02	<0.1	–
selenium	–	<0.05	0.03-0.16
sulfate	1020	275	515-986
cyanide	–	–	140
calcium	1300	–	–
potassium	110	–	–
lithium	2.8	–	–
magnesium	0.12	–	–
sodium	111	–	–
strontium	7.3	–	–
PCB	–	–	0.0001

– not analyzed

Sources:

A J. Hartien et al. 1986: maximum concentrations, shaking test

B E. Jøns 1984: DEV-S4 shaking test

C Z. Zhou and R. Dayal 1990: water as shaking solution, L/S 10

In Table 13, there are results of shakings of fly ash according to the German shaking test with leaching solutions with various pH values. The concentrations are almost the same; in other words, for the metals determined here, no differences can be detected in solubility as the pH of the leach solution changes. The concentrations are clearly below the comparison amounts in the table permitted in wastewaters.

In Table 13, metal concentrations of solutions obtained for fly ash by both EP and TCLP shaking tests have also been collected. There are not many differences in the concentrations; in TCLP shaking, the quantities are generally a little higher. If concentrations connected with these shaking tests are compared with the defined limits, the highest concentrations of arsenic and cadmium are over these limit values. When compared to household-water standards (Finland), for example, there are excesses for chromium, fluoride, and selenium. (C. C. Ainsworth and D. Rai 1987).

Table 13. Metal concentrations DEV-S4, EP, and TCLP) compared to permitted amounts

	(H. von Maier 1990) DEV-S4 shaking leach solution pH 4	pH 7	(C. C. Ainsworth and D. Rai 1987) EP shaking	TCLP shaking	Permitted concentrations (guidelines for reducing wastewater emissions, Austria)
As	0.0535	0.0549	0.001-16.4	0.01-2.68	0.1
F	–	–	0.28-7.45	0.29-6.05	–
Cd	<0.0001	<0.0001	<0.01-0.548	<0.01-0.564	0.1
Cr	0.0646	0.0633	<0.02-0.43	<0.01-4.64	0.1
Hg	<0.0001	<0.0001	<0.0001	<0.0001	0.01
Pb	<0.0001	<0.0001	<0.2-1.80	<0.2-2.78	1.0
Se	–	–	<0.001-0.112	<0.001-0.15	–
Zn	0.0005	0.0005	<0.002-111.0	<0.02-103.0	3.0

– not analyzed/Limit value not defined

The VTT (M. Wahlström and V. Pohjola 1987) has studied the leachability of fly ash from both coal and peat. In a shaking test (L/S 25), mostly sodium, potassium, calcium, sulfate, and chloride and smaller amounts of molybdenum, iron, zinc, barium, and arsenic leached. The dissolved portion of the total amount was generally below 10%.

In Germany (P. von Winske et al. 1991), the leaching behavior of fly ash and granulate and their effects on various soil types and groundwater near the surface were studied with lysimetry tests. In the lysimeters used in the study, there was a layer of fly ash and granulate of about 20 cm at the surface, and below this there was a layer of soil about 50-60 cm thick. The lysimeters were moistened with artificial rainwater, the pH of which was 4.2. The composition of the water that seeped through was compared to the composition of seepage water that had only passed through the soil. The flow-through had large amount of granulates, but small amount of fly ash. In the measurements, it was noted that the concentrations of substances that had seeped through was lower than the drinking-water standards for heavy metals, except for chromium. Aluminum leached extensively; the highest concentration with granulates was 28 mg/L Al^{3+}. The aluminum concentration and the amount of nitrate were found to correlate with each other. But all reactions were dependent on the soil type. Soil acts as a mechanical filter, and it has buffering effects. Compounds contained in the soil can also react with substances seeping through it, so that attachments occur.

In Danish studies (O. Hjelmar 1990), the leaching behavior of fly ash has been studied with lysimetry, column, and shaking tests. The results of the column and lysimetry tests correlate well with each other. The main components of seepage water filtering from alkaline and neutral fly ash are calcium, carbonate, sulfate, sodium, and potassium ions. Of the trace elements, arsenic, chromium, molybdenum, selenium, and vanadium were present in significant amounts, all of which form anionic compounds under alkaline conditions (for example, AsO_4^{3-}, CrO_4^{2-}). According to Hjelmar's equation describing leaching, it can take 250 years for the first seepage water to come from a fly-ash pile with a thickness of 10 m and a seepage rate of 200 mm/year.

4.3 Summary of leachability

Different amounts of materials leach from products, depending on their total concentrations and the leachability test used. Concentrations of harmful metals vary greatly, depending on the quality of the sample and the liquid/solid ratio used. The leachability of desulfurization gypsum was small in shaking tests; the composition of shaking solutions was even below the household-water standards in general.
When concentrations are compared directly, the concentrations of substances leaching from fly ash were somewhat higher than those of desulfurization products for chrome, for example.

5 TOXICITY OF DESULFURIZATION PRODUCTS AND FLY ASH

5.1 On the occurrence of metals in nature and their effects in general

In order to be able to estimate the effects of various substances contained in seepage water on the environment, the action of these substances in systems also has to be known. For example, metal concentrations vary in natural cycles, and some metals are even important nutrients and are thus necessary for plants and animals. A change in normal concentrations, either up or down, can effect the environment negatively. The form in which metals appear affects how they are transported, change chemically or biologically, and how they accumulate in various organisms.

Metals can be bound to oxides, hydroxides, or carbonates, they can be bound organically, or they can be in separate mineral phases.

Substances from ash or desulfurization piles spread into the environment by means of water. Water fauna, which are generally more sensitive than land fauna, suffer most from elevated concentrations. Variations in the pH, hardness, humus content, and particle quantities of water greatly affect the chemical form of metals and thus their biological accumulation and toxicity. The toxicity of metals is often inversely proportional to water hardness, which is due to the fact that calcium and magnesium reduce the permeability of biological membranes to metals. If the concentrations of many metals are high, the effects are often synergistic; in other words, the combined toxicity is greater than that of one individual metal. The mobility of metals increases as they bind to humus, which acts as a carrier and transports metals in the ecosystem (F. Norman 1991).

5.2 Toxicity of a solid product

5.2.1 Desulfurization products

We try to make use of solid products formed in desulfurization in road and ground construction, production of cement and concrete, etc., and generally in the construction industry. Gypsum from the dry method can replace natural gypsum. Desulfurization gypsum is also very suitable for the construction-material industry, etc., such as in the production of plasterboards and cement. Comparison of the chemical composition and other characteristics of natural gypsum and desulfurization gypsum is important in order to be able to estimate the health effects.

When gypsum is used in the construction industry, for example in the production of plasterboards, a human being can be exposed to gypsum in several phases, such as:

- the production phase, in which the construction material is produced,
- the processing phase, especially at the construction site,
- the usage phase, where the construction material is placed in walls,
- at the dump site, where construction wastes are collected.

A human being can be exposed to gypsum through the skin, respiratory tracts, and digestive tracts. One way of exposure through the skin is, for example, the use of gypsum in casts for bone fractures, from which no harmful effects have been observed. People are exposed through breathing mainly in the processing phase of construction materials, such as drilling, grinding, and sawing. Knowing the proportion and composition of dust that can be inhaled is essential in evaluating heath effects. In Germany, the maximum dust concentration for fine dust is 6 mg/mm^3. Exposure through the digestive tract can occur when gypsum dust is swallowed or when water is drunk into which substances have leached from the dump through the soil.

To map the health effects in Germany (J. von Beckert et al. 1991), the chemical composition of natural gypsum and desulfurization gypsum were studied, in particular the concentrations of substances that could have health effects, with special attention paid to investigating the use of gypsum in construction materials. Calcium, carbonate, chloride, iron, potassium, sulfate, and various trace elements such as arsenic, lead, cadmium, chromium, and mercury, etc., were analyzed from samples. Radioactivity, dioxins, and furans were measured from the samples, as were PAH compounds. In none of the samples were medically significant quantities of dioxins, furans, or PAH compounds found. Concentrations of mercury and selenium were clearly higher in desulfurization gypsum than in natural gypsum, while beryllium and cadmium quantities were larger in natural gypsum. Concentrations were small for all trace elements. On the basis of the values in Table 14, the danger of health risks can be excluded in the production and processing of products using both natural and desulfurization gypsum as raw materials. Metal concentrations were generally thousandths of the work-hygiene values in effect in Finland for the metals. Users of construction materials are exposed to substances that may possibly evaporate from boards 24 h a day and 7 days a week, and the group of exposed persons also includes children and the elderly. Even in the usage phase, there is no health harm from random exposure to gypsum dust.

Table 14. Comparison of maximum concentrations of metals contained in gypsum dust with Finnish work-hygiene limit values (8 h) and German guideline values (J. von Beckert et al. 1991)

	Maximum concentration NATURAL GYPSUM mg/kg	DESULFURIZATION GYPSUM mg/kg	Maximum concentration in gypsum dust µg/m³	Finnish work-hygiene limit values µg/m³, 8 h	Maximum gypsum-dust concentration from work-hygiene value	MAK value µg/m³	TRK value µg/m³
arsenic	4	3	0.024	10	1/400	–	100
beryllium	0.7	0.6	0.004	2	1/500	–	2
lead	21	22	0.130	100	1/800	100	–
cadmium	0.5	0.3	0.003	20	1/7000	–	–
chromium	25	10	0.150	50	1/300	–	100
cobalt	4	2	0.024	50	1/2000	–	100
copper	14	9	0.084	1000	1/12000	1000	–
manganese	130	200	1.200	1000	1/800	500	–
nickel	13	13	0.078	100	1/1300	–	500
mercury	0.09	1.3	0.008	50	1/6000	100	–
selenium	0.5	16	0.096	100	1/1000	100	–
tellurium	0.2	0.3	0.002	100	1/50000	100	–
thallium	0.2	0.4	0.002	100	1/50000	100	–
vanadium	26	8	0.156	500 (V_2O_5)	1/3000	50	–
zinc	40	50	0.300	5000	1/17000	5000	–

MAK Maximum workplace concentration value, GERMANY
TRK Technical guideline concentration value, GERMANY
* No MAK or TRK value is given for cadmium

The health risk from gypsum or plasterboards that enter dumps or landfills was estimated in the German study by comparing concentrations of trace elements with concentrations that usually appear in agricultural land. The concentrations contained in natural and desulfurization gypsum are significantly lower for the substances studied than the limit values given for agricultural land (Table 15); an exception is mercury, the concentration of which in desulfurization gypsum exceeds the maximum values given for agricultural land in effect in Finland. Because there are no chemical differences between natural and desulfurization gypsum, the effect of desulfurization gypsum on groundwater is comparable to the effects of a natural gypsum pile.

Table 15. Comparison of total concentrations of trace elements in gypsum samples with general concentrations in agricultural land and limit values of the European Community given for trace elements in agricultural land (J. von Beckert et al. 1991)

mg/kg	Total concentrations of trace elements, mg/kg		Total concentrations of trace elements in AGRICULTURAL LAND, mg/kg		
	NATURAL GYPSUM min max	DESULFURIZATION GYPSUM min max	General values (Germany)	Finnish limit values for agricultural land	EU limit values for agricultural land
arsenic	0.22-3.79	0.21-2.70	2-20	–	
lead	0.46-21.40	0.27-22.00	0.1-20	150	50-300
cadmium	0.03-0.30	0.003-0.29	0.1-1.0	0.5	1-3
chromium	0.65-24.90	1.02-9.72	2-50	200	100-200
fluorine	0.01-0.06	0.01-0.07	50-200	–	
nickel	0.3-13.40	0.3-12.90	2-50	60	30-75
mercury	0.006-0.05	0.03-1.32	0.1-1	0.2	1-1.5

Radioactivity was also determined in the study. The maximum concentrations determined from the gypsum samples for substances with natural radioactivity were 370 Bq/kg for potassium-40, 30 Bq/kg for radium-226, and 20 Bq/kg for thorium-232. The average concentrations for construction materials were 40 Bq/kg for radium and 30 Bq/kg for thorium. The values for the gypsum sample studies were smaller than these, so the use of gypsum materials in construction materials does not cause radiation-hygiene problems.

Summarizing the German study, there is no difference in terms of health between natural gypsum and desulfurization gypsum in chemical composition and trace-element composition. Desulfurization gypsum can be used in the production of construction materials without harm to health, according to the study.

Mutagenicity

In a German study (U. H. Cremer et al. 1988), desulfurization gypsum and natural gypsum were compared. Mutagenicity tests were conducted with the Ames test.

The test organisms were *Salmonella typhimurium* mutants that use histidine: TA 1535-1538, TA 98, and TA 100. 25 g desulfurization gypsum and natural gypsum were leached separately in a Soxhlet with 300 mL dichloromethane. After drying in a rotary evaporator, 5 mL dimethyl sulfoxide was added. From this solution, dilutions were made with five different levels. Test organisms were incubated in each dilution, both with and without addition of a liver enzyme, in three parallel series. Revertants were counted automatically with a computer. Averages were calculated from parallel samples, and the average rate of spontaneous mutation was calculated from these.

A substance is mutagenic if in one test with a *Salmonella typhimurium* strain a double rate of spontaneous mutation and a clear dosage-response connection is found, independent of the known substance concentration.

However, no increased number of revertants was found in any of the selected strains of *Salmonella typhimurum* as the sample concentration increased. According to this study, neither desulfurization gypsum from the wet method nor natural gypsum can be considered mutagenic when measured by the Ames test.

The toxicity of desulfurization gypsum in exposure through the respiratory organs has been studied by the German Barman (1986). In the study, test animals were given 25 mg gypsum dust in the trachea in an isotonic sodium-chloride solution. After the test period (24 h and 18 months), no clearly pathological reactions were observed and no signs of incipient lung fibrosis were found. Also, in this study, desulfurization gypsum was found to be non-mutagenic.

Toxicity of gases released in burning gypsum

Gases released when natural gypsum and plasterboards produced from desulfurization gypsum are burned were compared in a German study (H. J. Einbrodt 1989a). However, no significant differences could be observed in the composition of the gases. In the study, plasterboards were kept at 400 ± 2°C for one hour. Air was introduced into the space, which was mixed with gases evaporating from the boards. This air was directed into an exposure chamber with a volume of 260 L, in which there were 5 white rats. The test arrangement was according to DIN 53436. Gaseous decomposition products, such as carbon monoxide and carbon dioxide, were either measured continually or else individual samples were taken at intervals of 30 and 60 min. The samples were analyzed by photometry and gas chromatography. The behavior of the test animals was monitored for the entire 60-min test period. After this, blood samples were taken from the animals for determination of carbon-monoxide hemoglobin (COHb).

With this method, it was only possible to obtain an estimate of acute respiratory toxicity. In both gypsum plates, clear darkening was observed after the test. The smoke gases introduced into the exposure chamber contained, one hour after start of the test, 0.035 and 0029 vol% carbon monoxide, 0.10 and 0.08 vol% carbon dioxide, and 3.8 and 3.7 mg/m^3 sulfur dioxide, of which the first mentioned resulted from natural gypsum and the last from desulfurization gypsum. No sulfur, fluorine, or hydrogen cyanide was found in the smoke gases. Concentrations of formaldehyde and other aldehydes were below the detection limits for the method used. Both of the samples generated large amounts of smoke gases, but the test animals could still be observed well. The animals behaved normally. One hour after the end of the test, the measured values of blood carbon-monoxide hemoglobin were 22-24% COHb for rats exposed to smoke from natural gypsum and 16-18% for desulfurization gypsum, while the critical limit value is 35%.

Based on the results of the test, it can be noted that no high toxic concentrations of toxic components were found in the gaseous decomposition products formed at a temperature of 400°C. Also, the fluoride contained in desulfurization gypsum was not released as hydrogen fluoride. Replacing natural gypsum with desulfurization gypsum in the production of plasterboards does not affect the toxicity of gases formed in a burning situation, based on this study.

Summary of studies made on desulfurization gypsum

The desulfurization gypsum formed in a desulfurization plant has been frequently studied in Germany, because there are dozens of desulfurization plants based on the wet method there, and the efforts are being made to have it used primarily.

On the basis of the studies, desulfurization gypsum contains only small amounts of trace elements, as does natural gypsum. The same amount of exposure to acutely toxic compounds is connected with handling desulfurization gypsum as in handling natural gypsum.
Substances that leach from desulfurization gypsum and natural gypsum did not cause danger to groundwaters. Quantities of trace elements in the solutions were below the drinking-water standards. The amount of sulfate and fluoride ions exceeded the limit values in some cases, but similar excesses in natural gypsum have not caused any danger to health.
According to the grain-size distribution of desulfurization gypsum, only a small part of the particles are below 30 µm; in other words, particles that are blown from a desulfurization pile by the wind do not travel into human lungs. Also, material spread by wind does not cause danger to

agricultural operations, because the heavy-metal concentrations contained in the product are smaller than the concentrations in soil, according to the studies.
It was noted in mutagenicity tests made with the Ames test that neither desulfurization gypsum nor natural gypsum contains substances that cause mutations. In long-term animal tests, it was also observed that desulfurization gypsum does not contain components that increase connective tissue, in other words, fibrosis. Thus pneumoconiosis cannot follow respiratory exposure. Other respiratory diseases were also monitored, but no malignant growths or growth formations were observed.
Gases evaporating from construction boards are not toxic, according to the study. There were no differences between boards using desulfurization gypsum and natural gypsum as the raw material.
These results are valid only for desulfurization gypsum that derives from the desulfurization plant of a coal power plant (H. J. Einbrodt 1989b).

5.2.2 Fly ash

Mutagenicity

Mutagenicity studies of coal fly ash have been made with the Ames test, in which it has been found to be non-mutagenic. According to the tests, fly ash can be considered similar to inert dust in biological activity. According to the classification at that time, 10 mg/m^3 was given as the limit value in industrial areas (A. R. Reid 1984). Completely different results have been obtained in more recent studies in which fly-ash particles and seepage waters have been found to be mutagenic (D. El-Mogai et al. 1988). The cause of the mutagenicity has been proposed to be organic nitrogen compounds and some unidentified inorganic compounds.

Estimating the toxicity of fly ash with the earthworm test and plants

The growth and metal-binding of the earthworm *Eisenia fetida* and the plant *Cyperus esculentus* were studied in fly-ash samples, among others. In the study, samples were homogenized and dry fly ash was mixed with water. The pH of the mixture can be lowered from 8.5 to 7.4 with acetic acid, so the pH value would be about the same as in the comparison samples (Rhine-river sediment and sand sediment). The mixture was placed in plastic cylinders. The mixture was allowed to stabilize for a day before lettuce was planted. Earthworms were also added to the mixture (biomass 0.02 kg). The earthworms were removed after 31 days and washed, weighed, cleaned, and placed on filter paper for 48 h. The paper was replaced after 24 h, at which time the earthworms were again weighed, counted, and frozen. Leaves were cut from the plants after 45 days, about 5 cm about the ground surface. The green leaves and stems were washed, weighed, and frozen. Metal concentrations were determined from the samples. The metal concentrations determined from the fly ash and sediments are in Table 16.

Table 16. Metal concentrations (µg/g) in fly ash and sediments (distribution according to ASTM D3683; Cr, Cu, Ni, Zn ICP-AES; As, Pb, Sb, Se HG-AAS)

Material	Zn	Pb	Cu	Cr	Ni	As	Se	Sb
Rhine-river sediment	920	290	120	240	70	27	<5	5
Sand sediment	120	56	22	84	50	12	<5	<3
Fly ash	120 145	88 15	156 190	150 155	142 130	42 48	17 13	13 13

The growth of the plant that was the object of the study was very small, which was according to expectations. The growth difference between sediment and ash was not considered to derive from differences in toxicity but from the lack of nutrients, especially nitrogen compounds, in the fly ash. Metal concentrations in the plant were fairly small, except that arsenic, selenium, and antimony were slightly larger in plants grown in fly ash.

The earthworms lost weight during exposure to fly ash, which was normal in a test where food was not offered. No additional signs of toxicity were observed. Metal concentrations increased in comparison to background concentrations. Earthworms in fly ash accumulated more arsenic, selenium, and antimony.

Based on the study, fly ash cannot be considered toxic as such; in earthworms, no increased toxicity was observed after 32 days of exposure to 100% fly ash (J. M. Marquenie et al. 1988).

In Japan (J. Kohno et al. 1990), the effects of coal fly ash on the growth of various plants and the accumulation of trace elements were studied. On the basis of tests of the spreading of fly ash, no visible damage was observed to have developed in the plants. Based on the study, it was noted that fly ash does not cause any direct damage in the field. With large amounts of fly ash, however, fading and dropping of leaves was observed in the plants, and growth was prevented, which was due to excessive accumulation of boron in the plants.

Plants that had grown in soil containing fly ash accumulated increased concentrations of several substances. Arsenic, molybdenum, and selenium were in concentrations that might be toxic to cultivated plants. Also, animals that ate plants grown in soil containing fly ash accumulated high concentrations of selenium (D. El-Mogazi et al. 1988).

Exposure to fly ash through breathing

The effects of coal fly ash through respiratory tracts exposed to it have been much studied. According to information collected from the literature (P. K. Srivastava et al. 1987), fly-ash particles contain many cytotoxic and genotoxic metals and polycyclic aromatic hydrocarbons. In studies in which alveolar macrophages and hamster egg cells were used, it was noted that fly ash is cytotoxic, and the toxicity is affected by increasing the concentration and decreasing the particle size. Fly ash has also been observed to cause changes in the fine structure of the lungs, reducing the quantity of white cells, red cells, and hemoglobin, causing alveolar lipoproteinosis and pneumoconiosis. These effects were found to derive from chemical characteristics of fly ash and not from the particle shape. According to another source (G. Ferraiolo et al. 1990), the concentration of crystalline silicate particles (α-quartz) that cause pneumoconiosis is so small that there is no risk of getting pneumoconiosis while working in an environment within the given dust limits. Fly ash getting into the lungs through the trachea travels to the liver, causing harmful effects. It has been found to increase the activity of liver oxidase enzymes (P. K. Srivastava et al. 1987). Fly ash given through the trachea did not increase the dry or wet weight of lungs significantly. The collagen content of lungs increased significantly over time, depending on the dust concentration used (J. L. Kaw et al. 1989). The effect of fly-ash particles on the immunotoxicity of the lungs has been studied (D. E. Bice et al. 1987). Fly ash formed in dust combustion and quartz caused significant cellular changes in lungs and in pulmonary lymph nodes, whereas fly ash formed in fluidized-bed combustion had hardly any effect. Quartz and fly ash reduced the immune action of the pulmonary lymph nodes.

5.3 Toxicity of seepage water dissolving from products

Studying the toxicity of seepage leaching from fly ash from desulfurization products and coal is timely when we want to know about the possible effects of liquid seeping from a dump pile on the surrounding nature, plants, and soil.

5.3.1 Desulfurization products

In Denmark, a toxicity test has been performed on the lysimetry of the final product of the semi-dry method for seepage water. In it, the liquid/solid ratio was 0.36-0.42, at which an LC_{50} (24 h) value > 30% was obtained for *Daphnia magna* (M. Wahlström and V. Pohjola 1987). At a liquid/solid ratio of 0-0.19, the LC_{50} value for *D. magna* was 5-10% for a product of the semi-dry method which contained about 60% fly ash. When compared to the fly-ash toxicity results obtained in the same study, the acute toxicity of desulfurization waste was smaller or of the same size as the toxicity of fly ash. The VTT (J. Ranta et al. 1987) studied the toxicity of the seepage water of a stabilizate made from a semi-dry desulfurization product. In the water-flea test, the seepage-water stabilizate was more toxic than the corresponding seepage water from fly ash (Stabilize L/S 1.6 18%, fly ash L/S 1.2 66%). The seepage-water stabilizate contained significantly larger concentrations of cadmium, nitrite, and nitrate. On the Ames test, the seepage waters were not mutagenic.

Placing wastes formed in the burning of coal into the sea and the toxicity caused thereby has been studied (H. Rose et al. 1985). Here, the samples to be studied were leach solutions of a mixture of fly ash and desulfurization waste and a mixture of wastes formed in fluidized-bed combustion. A sea diatom (*Thalassiora [sic; Thalassiosina] pseudonana*) was subjected to leach solutions, and its growth by photosynthesis was monitored by measuring the quantity of suspended cells, chlorophyll concentration, and quantity of absorbed ^{14}C. The algae were subjected to even higher concentrations (10), but no significant effect was observed. Solutions of mixtures of products from one power plant inhibited the growth of algae for 1-2 days after the start of exposure.

Toxicity tests were performed in the Keskuslaboratorio [Central Laboratory] (KSL) on shaking solutions of desulfurization gypsum. The solutions studied were shaking solutions of Dutch and Danish gypsum, the liquid/solid ratios of which were 1:1 and 10:1 (Table 8). All leach solutions were found to be non-toxic according to the acute-toxicity test made according to SFS standard 5062; in other words, the LC_{50} values of the solutions were over 100%. When the concentrations of the various substances in the shaking solutions of Appendix 1 are compared to the existing extreme limit values, it is observed that the concentrations of the solutions are generally clearly below the toxicity limits for the substances determined. An exception is aluminum, the concentration of which when the Dutch gypsum is shaken (10:1) exceeds the LC_{50} value for *Daphnia magna*. The zinc concentration is also slightly higher.

A toxicity test has also been made on the final product of the Lifac desulfurization method with the water flea. As a result of the acute-toxicity test, an LC_{50} 24 h of 54% was obtained for the Lifac product. The solution studied was a shaking solution whose liquid/solid ratio was 1:1.

5.3.2 Sludge arising in the purification of wastewaters from desulfurization plants (filter cake)

IVO had an acute-toxicity test of leach solutions of shakings of so-called filter cake done for *Daphnia magna.* In the toxicity test, the liquid/solid ratios used for the leach solutions were 1:1 and 10:1. The chemical composition of the 1:1 shaking is in Table 10. In the test, it was noted that a shaking solution (L/S 1:1) approaching maximum concentration was toxic; 11.8% was obtained as its LC_{50} value. According to another German shaking method (L/S 10:1, 24 h of shaking), a toxicity result of 92.4% was obtained for the solution. In evaluating the cause of the toxicity, we can compare the concentrations of various substances with the LC_{50} values determined for the water flea (Appendix 1). Of the 1:1 solution substances the concentrations were clearly excessive for cadmium, copper, mercury, magnesium, and nickel. The quantity of leached chloride is also high. No clear single cause of the toxicity can be stated, but the toxic effect is probably the combined effect of many substances. The large difference between the toxicity of the shakings is due to the difference in the shaking methods and thus the concentrations of the leached substances. Closer examination of the substances, that affect the toxicity difference and their concentrations is not possible, because the chemical composition of one of the shakings (L/S 10:1) was not analyzed.

5.3.3 Fly ash

Toxicity tests of coal fly ash done on fish

Toxicity tests have been done on fish. In an American study (D. S. Cherry et al. 1987), the test fish were rainbow trout (*Salmo gairdneri*) and the bluegill (*Lepomis machrochirus*). The substances studied were base ash and fly ash from a coal power plant and, as a comparison material, salts of metals common in ash as mixtures with known concentrations were used. The structure of ash particles and the distribution of metals were examined with an electron microscope, on the basis of which it was observed that the metals are either in one pile or evenly distributed on the surface of the fly ash. It was observed that cadmium, copper, chromium, nickel, lead, mercury, titanium, arsenic, and selenium were enriched on the surface.

Base ash was not acutely toxic to either of the fish species studied at ash concentrations up to 1500 mg/L at various pH values (5, 7.5, and 8.5). Fly-ash particles were not acutely toxic to bluegill at concentrations up to 1360 mg/L. Rainbow trout was very sensitive to fly ash at ash concentrations of 4.3-20.5 mg/L when there were leached metals, but it was not sensitive at higher concentrations when there was only a little dissolved metal. When the metals had been acid-leached before testing, no deaths of rainbow trout were observed even at high concentrations (2350 mg/L). On the other hand, when the proportion of leached metals was large (50-90% of the total amount), fish mortality increased. Of the fish species studied, rainbow trout was twice as sensitive to exposure to a mixture of cadmium, chromium, copper, nickel, lead, and zinc as bluegill. In the sensitivity of the species, there were no differences between acidic (≤ 4) and alkaline (9.1) pH values. If the pH of the carbon fly-ash solution is between 6.0 and 9.0, acute toxicity to fish is considered to be due to some of the leached trace elements in the fly ash.

In an American investigation (J. J. Sulaway et al. 1983), an acute toxicity test was done on coal fly ash with flathead minnows (*Pimephales promelas*) and a bioaccumulation test was done on flathead minnows and green sunfish (*Lepomis cyanellus*). The solutions studied were the solutions of the EP shaking test. All samples were acutely toxic to flathead minnows. In the study, the toxicity of fly ash to fish was considered to be connected with the high pH, aluminum, ion-strength, and zinc values. On the basis of the study, it was not possible to identify a clear cause of the toxicity because of the complex composition of the solutions and the unknown antagonistic and synergistic effects.
In the bioaccumulation tests, fly-ash extracts were diluted to concentrations that were assumed to be at the sub-acute level. No significant differences in growth were observed between fish that were exposed to these solutions and control fish. Flathead minnows and green sunfish accumulated the same substances from the fly-ash extracts, that is, aluminum, boron, cadmium, manganese, molybdenum, and nickel, of which cadmium is probably the most important because of its toxicity.

The VTT (M. Wahlström and V. Pohjola 1987) have studied substances that leach from fly ash and the toxicity of seepage water. In Table 17, results of a toxicity test made on seepage waters with various solubility tests have been collected. The sample solutions were not very toxic, because the LC_{50} values for *Daphnia magna* varied between 65 and 100%. The solutions were also not toxic to fish after neutralization. Chronic toxicity was evaluated in an algae test, but none was found.

Table 17. Results of toxicity tests of coal fly ash (sample from Denmark) (M. Wahlström and V. Pohjola 1987).

WATER FLEA ***Daphnia magna***	**L/S dm^3/kg**	**LC_{50} 24 h,%**	**EC_{50} 24 h,%**
Column test	0-0.38	65	60
	9.1-9.5	98	66
Lysimetry test	0-0.021	80	48
	0.46-0.51	100	89
	0.46-1.2	100	84
FISH ***Rainbow trout***	**L/S dm^3/kg**	**LC_{50} 96 h,%**	
Lysimetry test	0-0.44	100	
	0.89-2.33	100	
ALGAE ***Selenastrum capricronutum Printz***	**L/S dm^3/g**	**LC_{50} 96 h,%**	**EC_{50} 96 h,%**
Lysimetry test	<0.5	> 25	> 25
	1	> 25	> 25

The same joint project also includes analyses of Danish coal fly ash. In these [analyses] significantly higher toxic values than the above were obtained. For *Daphnia magna,* the toxicity limits (LC_{50} 24 h) varied from 1.2 to 34% and for fish (LC_{50} 96 h) from 25 to 100%. In Table 18, the compositions of the fly-ash solutions studied in Denmark and in Finland are compared. The differences in toxicity values are considered to be due to the larger calcium and chromium concentrations in the seepage water obtained in the lysimetry test in Denmark. In the tests done in both countries, fly ash was more toxic to *Daphnia magna* than to fish.

Table 18. Composition of toxicity-test solutions (fly-ash lysimetry of seepage water)

mg/L	Done in Denmark	Done in Finland
pH	9.7-12.1	8.7-9.1
sulfate	1600-6800	8100
sodium	130-830	160
potassium	110-1000	370
calcium	570-5300	3100
arsenic	0.028-2	16
cadmium	<0.0003	0.0004
chromium	3.1-9.4	0.42
mercury	<0.0006	--
lead	<0.003	0.066
molybdenum	1.4-8.4	23
selenium	0.014-8.1	2

6 MODELS FOR ESTIMATING TOXICITY

In estimating the harm caused by dumping solid waste, the following should be taken into account:

- the nature of the waste itself and especially the possible binding of toxic components,
- environmental conditions (temperature, moisture, microbe activity, pH, etc.) where the waste is placed, and
- possible instability, variability, and toxicity of the waste.

Estimation models for harm caused by dumping

A decision-making model has been developed by assignment from the EPR (Electric Power Research Institute) of by-products arising from burning coal, with which an attempt is made to estimate the health and environmental effects of by-products, especially fly ash and base ash, and costs required to reduce the harm (D. Amaral, 1986). The model concentrates on the risks of exposure to substances that get into drinking water along with soluble trace elements and groundwater from the products. The purpose is to compare alternative means of improvement in regard to costs and reducing human exposure.

In Figure 5, there is a diagram of the principle of the model from which the dependency between the costs of the means of improvement and benefits to be obtained can be seen.

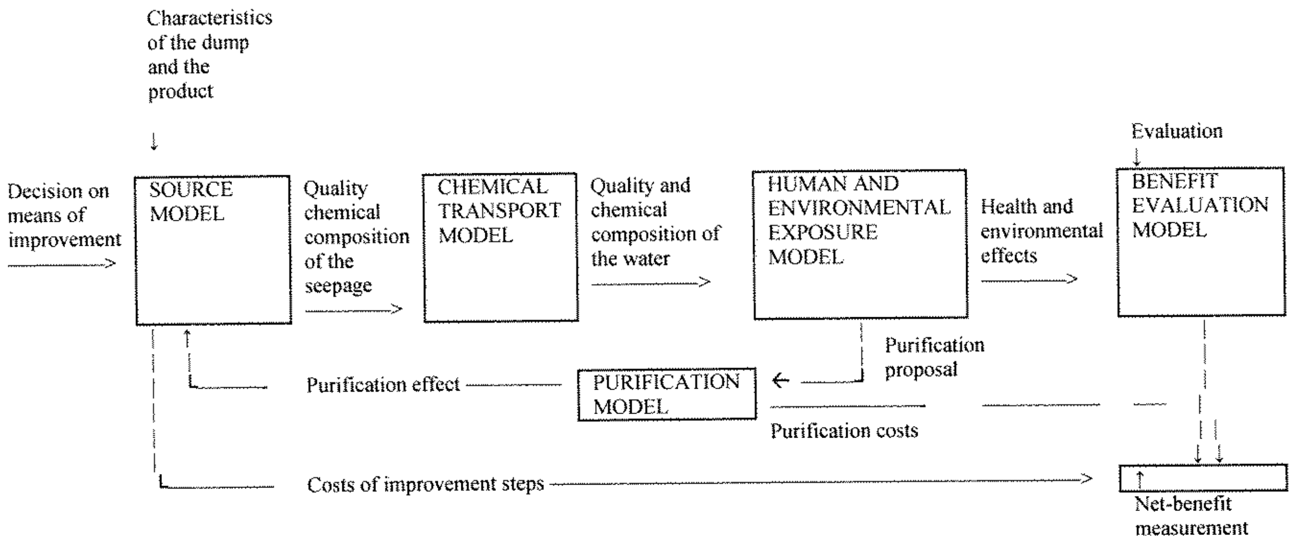


Figure 5. Evaluation model for harm caused by dumping and costs of improvement steps (D. Amaral 1986)

In the source model, the amount of waters seeping from a dumping area and their chemical compositions are estimated. In the chemical transport model, the seepage of the concentration of each chemical compound is estimated in various phases. The transport of chemical compounds is regulated by the movement of ground an surface waters and by chemical interaction occurring with the soil. In the human and environmental exposure model, exposure to the various chemicals is estimated. A person can be exposed at any point where drinking water is taken. Exposure levels are compared with the concentrations that require purification steps. In the purification model, the costs and effects of purification steps are estimated. Steps can include covering the area, building a clay barrier, removing ash and reconstructing the area, and pumping and treating groundwater. With this model it is possible to combine the information necessary to estimate the risks caused by wastes from power plants with the costs required to reduce these risks.

J. R. Kramer (1989) has developed a model for estimating the metals that leach from waste and their toxicity in general. In it, the elemental composition of the sample to be studied is first determined, the concentrations of which are compared to certain limit values (Table 19).

Table 19. Comparison values of the elemental analysis of waste in evaluating its danger (J. R. Kramer 1989)

mg/kg	Elemental analysis of the waste, limit values		Concentration values of the soil, average range	
arsenic	10	100	6	<1 – 93
barium	200	2000	554	15 – 5000
boron	1000	10000	34	<20 – 300
mercury	0.2	2	0.08	0.01 – 5
fluoride	480	4800	200	<10 – 4000
silver	10	100	–	–
cadmium	1	10	0.45	1-10
chromium	10	100	53	1 – 1500
lead	10	100	16	<10 – 700
selenium	2	20	0.03	<0.1 – 4
uranium	4	40	3	<2 – 4

If the concentrations of the waste to be studied are below these limits, there is no problem with regard to them. If the concentrations exceed them for one or more metals, we move to the next phase.

The second phase contains a series of different tests, depending on the quality and composition of the waste, which include, for example, studying the solubility of the metals at various pH values and investigating their nature. If the solubility values exceed the limits and the waste is thus classified as dangerous, the waste continues to be studied in a third phase. In it we try to connect the chemical characteristics of the waste with its toxicity. Toxicity can be studied, for example, according to the EHP (Environmental Hazard Profile) test method. It contains bioconcentration tests of algae, fish, and active sludge, investigations of storage, spreading, and excretion in rats, decomposition, and change with active sludge, and photochemical decomposition and mineralization. The main purpose of phase 3 is to determine the nature of the toxic material and to estimate what kinds of effects can be expected.

7 SUMMARY

Large amounts of desulfurization products and fly ash are produced annually in power plants which should be taken into consideration from the viewpoints of the environment, economics, and society. In general, the purpose of studying and analyzing harmful waste is to evaluate the health risks of appropriate placement and to identify certain effects caused by compounds, in order to be able to reduce the amount of toxic substances. Identification of the most harmful components would be a precondition for developing an appropriate waste-handling method. In this way, it would be possible to implement correct storage, transportation, and dumping procedures by which general health and safety and freedom from environmental damage could be guaranteed.

The composition of solid wastes produced in power plants is affected to a great extent by the quality and composition of the coal that is burned. For desulfurization products, the purity of the limestone or quicklime used as absorbent is also significant.

Of the desulfurization products, the concentrations of substances that leach from gypsum from the wet method are small, so there is no harm to the environment from this product, even when it is dumped. More problematic may be the sludge that remains from treating wastewaters from desulfurization, into which larger concentrations of various substances accumulate. This may require that the sludge be dumped into a special landfill. The amount of substances leaching from coal fly ash is generally larger than those that leach from desulfurization products.

According to most studies, seepage water from fly ash is acutely toxic to crustaceans and fish. Seepage water from desulfurization gypsum is not toxic. Seepage water from the sludge remaining from treating wastewaters in desulfurization plants has been found to be toxic to crustaceans.

The use of natural gypsum can be replaced completely with desulfurization gypsum. This has not been found to cause harmful characteristics in plasterboards, for example. Desulfurization gypsum has also not been found to have effects in exposure through the respiratory tracts. It is not mutagenic.

Coal fly ash has been found to be mutagenic in most studies. It had not been found to be directly harmful to plants. According to certain studies, fly ash has been found to be cytotoxic and to cause changes in the lungs.

Additional objects of study could be investigating the composition and leachability of the sludge arising in the treatment of wastewaters from desulfurization plants and their dependency on the power-plant and wastewater-treatment processes. With longer-range leachability studies, such as lysimetry tests, it would also be possible to estimate the substances that leach and their quantities better. Determination of chronic toxicity could also be necessary to obtain a broader picture.

SOURCES

[s. = p.; ss. = pp.; vsk. = vol.; Teoksessa = In the work]

Achord, R.D., Thompson, C.M. & Golden, D.M. 1990. Characterization of atmospheric fluidized-bed combustion by-products. 83rd annual meeting & exhibition, Pittsburgh, Pennsylvania, 24-29.6.1990. 24 s.

Ainsworth, C.C. & Rai, D. 1987. Chemical characterization of fossil fuel combustion wastes. Palo Alto USA, EPRI EA-5321. 136 s.

Amaral, D., North, D.W., Regulinski, S.G. & Wilson, D.S. 1986. A risk management framework for coal combustion by-product disposal. Teoksessa: 79th Annual Meeting of the Air Pollution Control Association, Session 12 Exposure assesment at hazardous waste sites, Minneapolis, Minnesota, 22-27.6.1986. 12 s.

C. Bartman 1986. The Biological Effect of a Smoke-gas Desulfurization Gypsum according to the Limestone Process. Aachen, Germany, NP-8770258. 83 p.

Bice, D.E., Hahn, F.F., Benson, J., Carpenter, R.L. & Hobbs, C.H. 1987. Comparative lung immunotoxicity of inhaled quartz and coal combustion fly ash. Environ. Res. (USA). v43:2. ss. 374-389

J. Beckert, H. J. Einbrodt, and M. Fisher 1991. Comparison of Natural Gypsum and REA Gypsum. *VGB Kraftwerkstechnik,* Vol. 17, 1/91, pp. 48-51.

F. von Burgmann 1986. Operating Experiences with Wastewater Treatment behind a Smoke-gas Purification System. *VGB Kraftwerkstechnik,* vol. 66, 9/86, pp. 866-871.

Cherry, D.S., van Hessel, J.H., Ribbe, P.H. & Cairns, J.Jr. 1987. Factors influencing acute toxicity of coal ash to rainbow trout (*Salmo gairdneri*) and bluegill sunfish (*Lepomis macrochirus*). Water Resour. Bull. (USA). v23:2. ss. 293-306

U. H. Cremer 1989. the Mutagenic Effect of Natural and REA gypsum in the Ames Test. *Wissenschaft und Umwelt ISU,* Vol. 4, 10/1989, pp. 202-205.

H. J. Einbrodt 1989a. Smoke-gas Toxicity after Thermal Loading of Plasterboards of Natural and REA Gypsum. Preliminary communication. *Wissenschaft und Umwelt ISU,* Vol. 4, 10/1989, pp. 211-212.

H. J. Einbrodt 1989b. Opinion on Further Processing of REA Gypsum from Coal Power Plants in the Construction Industry from the Viewpoint of Environmental Hygiene and Labor Medicine. *Wissenschaft und Umwelt,* Vol. 4, 10/1989, pp. 213-215.

H. J. Einbrodt and D. Prajsnar 1988. Investigation of Water-soluble Components of Natural and Smoke-gas Desulfurization Gypsums. *Wissenschaft und Umwelt ISU,* Vol. 3, 4/1989, pp. 194-198.

Electric Power Research Institute, 1986. Round-robin evaluation of regulatory extraction methods for solid wastes. EPRI-EA-4740, Palo Alto, USA.

El-Mogazi, D., Lisk, D.J. & Weinstein, L.H. 1988. A review of physical, chemical and biological properties of fly ash and effects on agricultural ecosystems. The Science of the total environment. 74. ss. 1-37

Ferraiolo, G., Zilli, M. & Converti, A. 1989. Fly ash disposal and utilization. J. Chem. Tech. Biotechnol., 47/90. ss. 281-305

D. von Fischer and W. Schenkel 1990. Requirement for the Storage of Wastes in the Federal Republic of Germany, Switzerland, and Austria. *Müll und Abfall,* Vol. 22, 1/90, pp. 2-13.

J. Harden, P. Elander, S. Kullberg, T. Lundgren, and B. Rosen 1986. Residual Products from Wet-dry Smoke-gas Desulfurization. Statens geotekniska Institut, FoU No. 10. 126 pp.

Hjelmar, O. 1990. Leachate from land disposal of coal fly ash. Waste Management & Research. 8/90. ss. 429-449

Jackson, L.P. & Sorini, S. 1987. Evaluation of the toxicity characteristic leaching procedure (TCLP) on utility wastes:Final Report. Palo Alto,USA. EPRI-CS-5355. 96 s.

E. Jøns 1984. Recycling of Waste Products from Smoke-gas Desulfurization. Final report for EFP development project No. 22528-3. A/S Niro Atomizer, Søborg. 39 pp. + appendix 14 pp.

Kaszynski, G.M. & Helm, S.T. 1987. Solid waste leachate data review: Volume 1: Summaries of fluidized-bed combustion and flue-gas desulfurization research programs. Argonne National Lab., IL, USA, Raportti nro ANL/EES-TM-334-Vol.1. 64 s.

Kaw, J.L., Khanna, A.K. & Waseem, M. 1988. In vitro cytotoxic and hemolytic potential of coal fly ash. Journal of Environmental Science and Health, Part A: Environmental Science and Engineering (USA). A23:7. ss. 711-723

Kaw, J.L., Khanna, A.K., Waseem, M. & Dogra, S. 1989. Pulmonary response to graded doses of coal fly ash in rats. Journal of Environmental Science and Health, Part A: Environmental Science and Engineering (USA). A24:7. ss. 745-765

Kohno, Y. ym. 1990. Effect of coal fly ash on the growth of several plants. Central Research Institute of Electric Power Industry, Tokio, Japani. Report no CRIEPI-U-89052.

Kramer, J.R. 1989. Characterization of leachable metals in industrial wastes: A suggested decision protocol. Teoksessa: Proceedings, Environmental research: 1989 Technology transfer conference, Toronto. Vol. II Liquid & solid waste, Analytical methods, Environmental socio-economics. ss. 246-253

A. Lanqi and E. Nikunen 1983. Toxicity Testing of Industrial Wastewaters and Chemicals. Publications of Central Laboratory Corp. 111 pp.

L. Laitinen 1990. Shaking Tests Used in Leachability Studies of Wastewater and Environment Administration, Technical research Center, work report. 6 pp. + appendix 12 pp.

H. von Maier 1990. Emissions of Heavy Metals Escaping with Smoke Gas and Passing through Filters from Peat-fueled Systems. *VGB Kraftwerkstechnik,* vol. 71, 10/90, pp. 876-881.

Marquenie, J.M., Crawley, D.K., De Jong, P. & Jenner, H.A. 1988. Growth and metal uptake of the plant *Cyperus esculentus* and the worm *Eisenia fetida* in a worst-case experiment on coal fly ash and Rhine sediment. KEMA Scientific & Technical Reports 6(4), Netherlands. 6 s.

Meij, R. 1989. Tracking trace elements at a coal-fired power plant equipped with a wet flue-gas desulphurisation facility. Kema Scientific & Technical Reports 7 (5). ss. 267-355

Murarka, I.P. & Friedman, D. 1988. Round-robin study of leaching methods as applied to solid wastes from coal-fired power plants. Symposium on solid waste testing and quality assurance. Washington, USA. ss. 112-129

Neuhauser, E.F., Loehr, R.C. & Malecki, M.R., 1986. Contact and artificial test soil tests using earthworms to evaluate the impact of wastes in soil. Teoksessa: Hazardous and industrial solid waste testing: Fourth Symposium, ASTM STP 886, toim. J.K. Petros, Jr., W.J. Lacy & R.A. Conway, American Society for Testing and Materials, Philadelphia, ss. 192-203

E. Nikunen, R. Leinonen, and A. Kultamaa 1990. Environmental Characteristics of Chemicals. Helsinki, Ministry of the Environment, report 91/1990. 1096 pp.

F. Norman 1991. Prioritization of Inorganic Substances in Coal and Incineration Ashes with a View toward Environmental Effects. IVL report B 1010. 58 pp. + appendix 33 pp.

E. Panula-Nikkilä and M. Äijälä 1986. Solubility of Coal Ash in Water. Espoo, Finland Technical Research Center. Studies 451. 57 pp. + appendix 7 pp.

Peterson, S.A., Greene, J.C. & Miller, W.E., 1990. Toxicological assessment of hazardous waste samples extracted with deionized water or sodium acetate (TCLP) leaching media. Teoksessa: Waste testing and quality assurance: 2nd Vol., ASTM STP 1062, toim. D. Friedman, American Society for Testing and Materials, Philadelphia. ss. 107-129

J. Ranta, M. Wahlström, J. Ruohomäki, T. Häkkinen, and P. Lindroos 1987. Desulfurization Wastes of Coal Power Plants. Preliminary study. Espoo, Finland Technical Research Center Communications 741. 140 pp. + appendix 6 pp.

J. Ranta, M. Wahlström, P. Lindroos, and T. Häkkinen 1990. Desulfurization Wastes of Coal Power Plants. Environmental Effects and Recycling. Helsinki, Ministry of Commerce and Industry, series D:182. 95 pp.

Reid, A.R. 1984. Proceedings of the second international conference on ash technology and marketing, London. 725 s.

SFS 5062. Water Studies, Determination of Acute Toxicity with the Water Flea *Daphnia magna Straus*. December 31, 1984. 1st ed. 9 pp.

SFS 5072. Water Studies. Toxicity Test with an Algae Culture. March 24, 1986, 1st ed., 2 pp.

SFS 5073. Water Studies. Determination of Acute Toxicity with the Rainbow Trout *Salmo gairdneri Richardson, teleostei, salmonidae*. Static and semi-static Method. March 24, 1986, 1st ed., 8 pp.

Sloot, van der H.A., Piepers, O. & Kok, A. 1984. A standard leaching test for combustion residues, BEOP-31. 50 s.

Suloway, J.J., Roy, W.R., Skelly, T.M., Dickerson, D.R., Schuller, R.M. & Griffin, R.A. 1983. Chemical and toxicological properties of coal fly ash. Illinois, USA, Environmental geology notes 105. 70 s.

Srivastava, P.K., Singh, Y., Tyagi, S.R. & Misra, U.K. 1987. Induction of hepatic drug metabolizing enzymes by coal fly ash in rats. Environ. Res.(USA), v44:2. ss. 228-237

Recycling Plan for Residues from Coal Power Plants, Part III: Residues from Water and Wastewater Treatment. *VGB Kraftwerkstechnik,* Vol. 70, 12/90, pp. 1033-1041.

M. Wahlström and V. Pohjola 1987. Leaching of Metals from Peat Fly Ash. Espoo, Finland Technical Research Center. Studies 483. 91 pp. + appendix 50 pp.

P. von Winske, W. Degro, F. Kiefer, A. Frank-Fuchs, and H. Schneider, 1991. Behavior, Effects, Usage, and Marketing of the Power-plant By-products Granulate and Fly Ash. *VGB Kraftwerkstechnik,* Vol. 71, 7/91, pp. 700-713.

Ymparistöministeriö 1991. Use of Purification Sludge in Agriculture. Helsinki, Ministry of the Environment, Environmental Protection Section Guideline 4/1991. 43 pp.

TOXICITY LIMITS FOR SUBSTANCES APPEARING IN SEEPAGE WATERS

	LC_{50} mg/L for CRUSTACEANS	**LC_{50} mg/L for FISH**	**OTHER LIMITS, mg/L**
Al	**1.4** 48 h *Daphnia magna* **6.57** 48 h *Asellus aquaticus*	**0.56** 28 d *Salmo gairdneri*	**0.68 EC_{50}** crust. 21 d rpd *D. magna*
NH_3	**3.33/2.5/1.9** 1 d/2 d/4 d *A. aquaticus*	**0.56** 72 h *S. gairdneri* **0.16-1.1** 96 h *S. gairdneri*	**0.02 $LOEC_{50}$** fish *S. gairdneri* NOTE! NH_4^+ less toxic at higher pH values
Sb	**> 530** srv act 48 h *D. magna*	**0.66** srv schr 28 d *S. gairdneri*	–
As	**2.85** 48 h *D. magna*	**0.55** 24 d *S. gairdneri*	**1.4 EC_{50}** crust. 21 d rpd *D. magna*
Ba	**410** srv act 48 h *D. magna* **13.5** srv act 48 h *D. magna*	**42.7** srv schr 28 d *S. gairdneri*	**8.9 EC_{50}** rpd schr 21 d *D. magna*
Be	**1.0** srv act 48 h *D. magna*	**0.38** *srv schr 28 d* *S. gairdneri*	–
B	–	–	–
Hg	**0.65/0.199** Hg(II) 48 h/96 h mbt *A. aquaicur* **0.006-0.020** 48 h *D. magna*	**0.005** 28 d *S. gairdneri* **0.16** 96 h *Lepsmis macrochirus*	**0.006-0.02 EC_{50}** crust. 48 h *D. magna*
F	–	–	–
P	–	–	–
Ag	**0.0006-0.0550** 48 h	**0.10** 72 h *Cyprinus carpio*	**0.01 EC_{50}** 48 h mbt *D. magna*

	D. magna	**0.047** 72 h *Carassius auratus* **0.029** 96 h *S. gairdneri*	
Cd	**1.32** Cd (II) 96 h mbt *A. aquaticus* 4.58 Cd (II) 48 h mbt *A. aquaticus* 0.005 48 h *D. Magna*	**0.016-0.017** act *S. gairdneri* **0.14** 28 d *S. gairdneri*	**2.1 LC_{50}** algae *Chlorella pyrenoidosa*
K	**97** srv schr 48 h *D. magna* **450** srv act 96 h *Nitocra spinipes*	–	**68 EC_{50}** crust. rpd schr 21 d *D. magna*
Ca	–	–	–
Cl		**0.014/2.1/0.037** srv act 96 h *S. gairdneri*	**0.003 NOEC** crust. rpd schr *D. magna*
Co	**0.021** 48 h *D. magna*	**0.490** 28 d *S. gairdneri*	**0.018 EC_{50}** alga rpd 96 h *Selenestrum capricornutum* **1500 mg/kg LDL_0** mamm. orl-rat **20 mg/kg LDL_0** mamm. orl-rbt
Cr III	**2** 48 h *D. magna* **442/937** 96 h/48 h mbt *A. aquaticus*	**4.4** 96 h *S. gairdneri* **58.5** 96 h *Branchydanio rerio*	**0.6 EC_{50}** 21 d rpd *D. magna*
Cr VI	**1.84** 96 h *Macrobrachium lamanai*	**0.19** 28 d *S. gairdneri* **200** 96 h *Mystus vittatus*	**0.025 LOEC** fish grw schr *S. garidneri* **0.340 LOEC** fish srv grw schr

			S. garidneri
Cu	**0.026/0.044** 48 h *D. magna*	**0.11** 28 d *S. gairdneri*	**0.12 mg/kg TDL_0** mamm. orl-hmn

	LC_{50} mg/L for CRUSTACEANS	LC_{50} mg/L for FISH	OTHER LIMITS, mg/L
Pb	**0.3** 48 h *D. magna* **64.1/120** 96 h/48 h mbt *A. aquaticus*	**0.22** 28 d *S. gairdneri* **26** 96 h *Colisa fasciata*	**450 mg/kg TDLo** mamm. ihl-hmn **0.01 mg/m^3 TDL$_0$** mamm. ihl-hmn
Mg	**190** 48 h *D. magna* **720** 96 h *N. spinipes*	**1355** 28 d *S. gairdneri*	**125 EC$_{50}$** crust. 21 d prd *D. magna*
Mn	**5.7** 48 h *D. magna* **333/771** Mn (III) 96 h/48 h mbt *A. aquaticus*	**2.91** 28 d *S. gairdneri*	**3.1 EC$_{50}$** algae rpd schr *S. capricornitum [sic; capricornutum]* **5.2 EC$_{50}$** crust. 21 d rpd *D. magna*
Mo	–	–	–
Na	**1480** 48 h *D. magna*	–	**1020 EC$_{50}$** crust. 21 d rpd *D. magna*
Ni	**0.13** 48 h *D. magna* **119/435** Ni(II) mbt 96 h/48 h *A. aquaticus*	**7.1/35.5** 96 h *S. gairdneri* **0.05** 28 d *S. gairdneri*	**5 mg/kg LDL$_0$** mamm. orl-gpg
NO_3	–	**0.3-12** 96 h *S. gairdneri*	–
NO_2	**28** 96 h *Procambarus clarcii [sic; clarkii]*	**0.6-31** 96 h *S. gairdneri*	**2750 LD$_{50}$** mamm. orl-mus
Fe	**5.9** 48 h *D. magna* **81.1/183** Fe(III) 48 h *A. aquatics*	**80** 24 h *Alburnus alburnus* **75** 24 h *Platichthys flesus* **230** 24 h *Perca fluviatilis*	**5.2 EC$_{50}$** crust. 21 d rpd *D. magna*

	124 Fe(II) 96 h *A. aquaticus*		
Zn	**0.16** 48 h *D. magna* **1** 57 h *Gammarus pulex*	**0.8** 96 h *S. gairdneri*	**10 LC_{50}** algae 96 d *Navicula* **124 mg/m^3 TCL_0** mamm. 50 min ihl-hmn
Se	**0.43/3.87** 48 h *D. magna*	**6.7** 96 h *Cyprinodon variegatus* **5.17** 28 d *S. gairdneri*	–
SO_4	–	–	–
S^{2-}	–	–	–
SO_3	–	**5.7** 96 h *Pugnose Minnow*	–
CN	–	**0.057** 96 h *S. gairdneri*	**1.8 EC_{50}** crust. rpd 48 h *Daphnia* **3 mg/kg LD_{50}** mamm. rpd ipr-mus
Ti	**2.2** 48 h *D. magna*	**0.18** 28 d *S. gairdneri*	**4.412 mg/kg LDL_0** mamm. unk-man **5.714 mg/kg LDL_0** mamm. orl-man
Sn	**42** 48 h *D. magna*	**0.42** 28 d *S. gairdneri*	**1.5 EC_{50}** crust. 21 d rpd *D. magna*
V	**2** 23 d rpd *D. magna* **3.4-4.8** 48 h *D. magna*	**0.17** 28 d *S. gairdneri* **8.0-19.4** 48 h *B. rerio*	**0.8-4.0 EC_{50}** crust. 48 h srv *D. magna*

ABBREVIATIONS AND EXPLANATIONS

METHODS OF EXPOSURE

ihl	inhalation	hengitysteitse
ipr	intraperitoneal	vatsaonteloon
orl	oral	suun kautta
ukn	unknown	ei tiedossa

SPECIES EXPOSED (ABBREVIATIONS)

gpg	guinea pig	marsu
hmn	human	ihminen
man	man	mies
mus	mouse	hiiri
rat	rat	rotta
rbt	rabbit	kaniini

OBJECT OF STUDY

grw	growth	kasvu
mbt	mobility	liikkuvuus
rpd	reproduction	lisääntyminen
srv	survival	henkiinjääminen

DURATION OF EXPOSURE

act	acute	akuutti
schr	semichronic	semikrooninen

ABBREVIATIONS FOR TOXICITY

LD_{50} = dose that kills 50% of the test organisms

LC_{50} = concentration that kills 50% of the test organisms during the test period

LDL_0 = smallest dose that has been found to increase mortality

LCL_0 = smallest concentration that has been found to increase mortality

TDL_0 = smallest concentration that has been found to cause toxic effects in humans or carcinogenic, neoplastigenic, or teratogenic effects in test animals or humans

TCL_0 = smallest concentration that has been found to cause the effects mentioned in the preceding point

EC_{50} = concentration that causes some separately defined toxic effect in half of the test organisms during the test period

LOEC = smallest concentration that causes some separately defined toxic effects during the test period

NOEC = concentration at which no toxic effects are found

SPECIES EXPOSED

Fish

Alburnus alburnus	bleak
Branchydanio rerio	zebra fish
Carassius auratus	goldfish
Colisa fasciata	banded gourami
Cyprinodon variegatus	sheepshead minnow
Cyprinus carpio	carp
Lepomis machrochiru	bluegill
Mystus vittatus	striped catfish
Perca fluviatilis	perch
Platichthys flesus	flounder
Salmo garidneri	rainbow trout

Crustaceans

Asellus	water lice
Daphnia magna	water flea
Gammarus pulex	river shrimp
Macrobrachium lamarrei	freshwater prawn
Nitocra spinipes	harpacticoid copepod
Procamparus clarkii	red swamp crayfish

Algae

Chlorella pyrenoidosa	green algae
Navicula	diatom
Selenastrum capricornutum	green algae

SOURCE:

E. Nikunen, R. Leinonen, and A. Kultamaa 1990. Environmental Characteristics of Chemicals. Ministry of the Environment, report 91/1990, VAPK, Helsinki, 1096 pp.

ATTACHMENT G

HEALTH EFFECTS OF GYPSUM DUSTS FROM OCCUPATIONAL EXPOSURE

The OMS Ltd.
Occupational Medicine Specialists

300 West Adams Street, Suite 835, Chicago, IL 60606
Tel: (312) 762-2959 (800)359-1979 x 362 Fax: (312) 551-2287

Shirley A. Conibear, M.D., M.P.H.
Occupational Medicine
Toxicology
Certified Medical Review Officer
Travel Medicine

Raja K. Khuri, M.D., M.P.H.
Occupational Medicine
Internal Medicine
Certified Independent Medical Examiner
Certified Medical Review Officer
Travel Medicine

Brian C. Svazas, M.D., M.P.H.
Occupational Medicine
Certified Medical Review Officer
DOT Physicals
Travel Medicine

May 5, 2006

To Whom It May Concern:

My name is Shirley Conibear, MD, MPH. I am a licensed medical doctor and am Board Certified in Occupational Medicine. I have practiced in my specialty for over 30 years. I have served as medical consultant to USG Corp for over 25 years. In this position, I have designed and implemented a medical surveillance program for over 5000 of USG's production workers, about half of whom mine, quarry and manufacture gypsum wall board. Medical monitoring of these workers includes pulmonary function testing (PFT), PA chest x-ray read by a B Reader/radiologist, and medical history. Testing is conducted annually although x-rays are taken at less frequent intervals. I personally review all the medical findings of employees with abnormalities of PFTs and chest x-rays and respiratory complaints.

I have not observed an excess of lung disease, a pattern of x-ray abnormalities indicative of fibrotic changes or a pattern of symptoms suggestive of occupational lung disease. There is no discernable difference between the findings in workers in the plants that use synthetic gypsum versus the plants that use mined or quarried gypsum. I have not observed a pattern of health effects on any other organ systems based on other medical testing conducted as a part of the medical surveillance program which includes complete blood count and blood chemistries. These findings are consistent with the medical literature regarding exposure to gypsum dust in the United States.

Shirley Conibear

ATTACHMENT H

COMPARISION OF NATURAL GYPSUM AND FGD GYPSUM

VGB TECHNISCHE VEREINIGUNG DER GROSSKRAFTWERKSBETREIBER E.V.

VGB
Technical Scientific Reports
"Thermal Power Plants"

Comparision of Natural Gypsum and FGD Gypsum

Studies for a comparative assessment of the health impact of natural gypsum and FGD gypsum from coal-fired power plants with a view to their use in the manufacture of building materials

– VGB-TW 707 e –

ISSN-No. 0937-0188

VGB TECHNISCHE VEREINIGUNG DER GROSSKRAFTWERKSBETREIBER E.V.

VGB
Technical Scientific Reports
“Thermal Power Plants“

Expert's Opinion Report

on

“Studies for a comparative assessment of the health impact of natural gypsum and FGD gypsum from coal-fired power plants with a view to their use in the manufacture of building materials”

(Comparison of Natural Gypsum and FGD Gypsum)

Study commissioned by

— VGB-FORSCHUNGSSTIFTUNG, Essen
(VGB research project 88)

— Bundesverband der Gips- und Gipsbauplattenindustrie e.V., Darmstadt

Report prepared by

— **Professor Dr. med. J. Beckert,** Institut für Hygiene der Medizinischen Universität zu Lübeck (Hygiene Institute of Lübeck Medical University) (project coordinator)

— **Professor Dr. med. H.J. Einbrodt,** Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen (Hygiene and Occupational Medicine Institute, RWTH)

— **Dr. phil. M. Fischer,** Director and Professor at the Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes, Berlin (Institute for Water, Soil and Air Hygiene at the Federal Health Office, Berlin)

– VGB-TW 707 e –

Published by
VGB TECHNISCHE VEREINIGUNG
DER GROSSKRAFTWERKSBETREIBER E.V.

Obtainable from:

VGB-KRAFTWERKSTECHNIK GmbH
— Verlag technisch-wissenschaftlicher Schriften —
P.O. Box 10 39 32, D-45039 Essen

Contents

1 Topic of investigation

Samples of natural gypsum and gypsum obtained from the desulphurization of flue gases in coal-fired power plants (FGD gypsum) are to be analyzed as the basis for a comprehensive assessment of the health impact of gypsum when used as an input material for the manufacture of building materials. Particular attention is to be dedicated to investigating whether there is any difference in terms of health impact between natural gypsum and FGD gypsum.

2 Basic considerations

2.1 Building materials

The practice of classifying building materials according to whether they are of natural or synthetic origin is unsuitable as a criterion for assessing their potential impact on human health. The crucial factor determining the health impact of building materials is the substances present as constituents in the input materials and how those substances may affect the human organism. Of particular importance in this context are the concentration in which the substances act upon the organism and the duration of exposure. In the holistic consideration required of such studies today, four levels can be distinguished for the purposes of assessing the health impact of the substances in question. These four assessment levels refer to the following exposure environments:

— **production**, in which the building material is manufactured,

— **processing**, especially on the construction site,

— **application**, in which the building material is used in the construction of enclosed living or working areas, and

— **disposal**, in which the building materials remaining after demolition of a structure are consigned to ultimate storage as building rubble (dumping) or are utilized (e.g. by thermal waste incineration).

This holistic consideration calls for an exhaustive analysis of all the component substances that are present in the building materials and that may be of relevance to human health, and for studies to determine the concentrations of these substances which could affect the skin, the respiratory or the digestive tract of the human organism.

2.2 Gypsum-based building materials

Gypsum – dihydrous calcium sulphate ($CaSO_4 \cdot 2H_2O$) – is one of the oldest raw materials used in the manufacture of building materials. Gypsum occurs extensively in mineral form in the crust of the earth. This form is known as natural gypsum. However, gypsum is also obtained as a by-product of certain chemical and technological processes. A particularly prominent example of this type is the gypsum formed in the flue gas desulphurization facilities of coal-fired power plants, known for this reason as FGD gypsum.

When dihydrous calcium sulphate, also known as crude gypsum, is exposed to certain thermal processes, calcium sulphate phases with little or no water of crystallization are formed, and these later combine with free water to form again dihydrated set gypsum. These processes, known as dehydration and rehydration, form the basis of gypsum technology; they are indispensable to the use of gypsum in the production of building materials, whether in the form of wallboards or plasters [30, 33].

Gypsum-based building materials were already in use in classical times, and large-scale use of gypsum epitomized the baroque and rococo periods. Since the 19th century, the demand for gypsum has been on the rise in many parts of the globe, world-wide consumption attaining about 78 million tonnes per year (1984 data) [34]. In Germany, nearly 3 million tonnes of raw gypsum was used in the manufacture of building materials in 1987, about 2.5 million tonnes of that figure processed by the gypsum industry and 0.5 million tonnes by the cement industry [31].

Natural gypsum

Natural gypsum deposits occur in many parts of the world, having been formed in early geological ages as sedimentary rock left behind by the evaporation of ocean brine. In line with their marine origins, natural gypsums also contain small quantities of those substances that are normally present in solution in seawater. Centuries of experience have shown that natural gypsum is a versatile and unproblematic raw material that can be used to manufacture building materials for finishing the interiors of residential and business premises of all kinds.

FGD gypsum

The combustion of sulphurous fossil fuels such as hard coal, lignite (and fuel oil) produces sulphur dioxide (SO_2) which, if it is not removed in a flue gas desulphurization plant, escapes into the atmosphere with the flue gases. To preserve the quality of the air and to protect man and his environment from harmful effects of SO_2 and its derivatives, the German authorities in 1983 passed the Grossfeuerungsanlagenverordnung [28], an ordinance governing combustion of fossil fuels in industrial-scale facilities, which established the legal basis making it compulsory for fossil-fueled power plants to be fitted with flue gas desulphurization (FGD) facilities. As of 30th June 1988, all industrial-scale combustion installations intended for long-term operation have been required to be equipped with flue gas desulphurization facilities that retain at least 85 %, in many cases even more, of the SO_2 entrained in their flue gases.

Of all the flue gas desulphurization processes available, limestone-based scrubbing processes have proved most popular in Germany, accounting for 87 % of the total desulphurized power plant capacity [13]. These processes use limestone ($CaCO_3$) or quicklime (CaO) to convert the sulphur dioxide present in the flue gases into gypsum ($CaSO_4 \cdot 2\,H_2O$). This end product of the desulphurization process is known as FGD gypsum. Currently, about 2.2 million tonnes of FGD gypsum per year are produced in hard-coal-fired power plants and about 1.1 million tonnes per annum in lignite-fired power plants [17].

The reason why the limestone-based scrubbing processes enjoy such widespread acceptance is that they afford at one and the same time a high desulphurization efficiency, a high level of reliability in operation, and as a rule also the best economic viability by comparison with other processes. Also, Germany has large deposits of high-quality limestone, which means that the input materials used in the flue gas desulphurization process are of a quality conducive to producing FGD gypsum that is suitable for use in economically meaningful applications [24].

The desulphurization process itself takes place in scrubbing towers in which the flue gases are brought into contact with an aqueous suspension containing powdered limestone or slaked quicklime as its alkaline component. The SO_2 is washed out by the water, oxidized to sulphate SO_4^{2-} in the aqueous solution, and precipitated with calcium from the limestone/quicklime into dihydrous calcium sulphate ($CaSO_4 \cdot 2\,H_2O$), gypsum. The gypsum crystals are separated out of the suspension as a moist, fine crystalline powder with the aid of centrifuges or filters.

In all flue gas desulphurization facilities, the solids in the flue gases (the fly ash) are separated out by means of electrostatic filters before the flue gases enter the scrubbing tower. The gases are then either passed directly to the SO_2 absorber or are first treated in a pre-scrubbing stage. In the latter case, post-scrubbing of the gypsum at the centrifuging stage can be dispensed with, otherwise it is common practice to wash out the water-soluble components – in particular chloride – during centrifuging or filtering, if the FGD gypsum is intended for commercial use.

High-purity powdered limestone or quicklime will generally produce FGD gypsum with a purity in excess of 95 %, the remaining fraction consisting almost entirely of surplus limestone and non-water-soluble inert materials. This high level of purity is assured by the process steps of electrostatic filtering and possibly pre-scrubbing of the flue gases and post-scrubbing of the gypsum in the centrifuge. The quality of the FGD gypsum is the subject of contractual agreements with the purchasers and processors to ensure that the gypsum is suitable for further processing into high-quality products for the construction materials industry [12].

3 Subjects of investigation

3.1 Analyses and quantitative determinations to be performed

It was specified that a quantitative determination should be performed for all parameters of relevance to human health and characteristic of the origin of the respective gypsum.

Chemical analyses

ammonium, calcium, carbonate, chloride, water of crystallization, cyanide, fluoride, iron, magnesium, nitrate, pH value in the suspension, phosphate, potassium, sodium, sulphate, sulphite.

Trace elements

Arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, tellurium, thallium, vanadium, zinc.

Radioactivity

Natural radioactive substances.
Man-made radioactive substances.

Dioxins and furanes

Polycyclic aromatic hydrocarbons.

3.2 Possible effects on the human organism

An analysis of the substances present does not in itself permit any assessment of their implications for human health. These will depend primarily upon how those substances act upon the human organism. The areas in which environmental factors can act upon the human organism are known as contact zones. For the purposes of assessing the potential health impact of gypsum, there are three contact zones that must be taken into account:

The skin

Gypsum can be used as a raw material or as a building material. The long history of the successful use of gypsum in medicine, e.g. to assist in the healing of broken bones, proves that detrimental effects on health due to skin contact can be ruled out.

The respiratory tract

Gypsum can affect the respiratory tract, that is to say the bronchial tubes and the pulmonary alveoli, only in the form of inhalable dust. Exposure to gypsum in this form is possible in the production environment, in the processing environment, and in the application environment when work is performed on the finished gypsum product, e.g. when drilling holes or when sawing or cutting gypsum boards, as the user of a building may occasionally have to do. However, since drilling and sawing of gypsum boards is not common practice at the application end, users will be exposed to gypsum powder only by way of rare exceptions.

The digestive tract

Contact with gypsum and its component substances in the digestive tract may come about if inhaled gypsum particles are swallowed in the saliva and especially if they find their way into the drinking water. However, the latter is possible only if the soluble components of gypsum deposited in a landfill find their way unchanged through the soil and into the groundwater, which is then used as drinking water.

3.3 Quantification of exposure to gypsum and its active components

An assessment of the health impact of gypsum must focus on the concentrations of the gypsum component substances to which the organism is exposed in the various environments in which it may come into contact with gypsum.

The production and processing environments

The gypsum concentrations occurring here relate to the fine dust which can enter the lungs. In Germany, there is a statutory limit on the amount of airborne dust present in production and processing facilities during continuous operation. This limit is known as the maximum workplace concentration (MAK) and is set at 6mg fine dust/m^3 air [8]. If the dust concentration in any working area is higher, suitable safety measures such as the wearing of masks or the provision of forced extraction equipment must be implemented. Thus, the statutory dust limit can be taken as the highest concentration that can possibly be encountered at the workplace during continuous operation.

The application environment

Once the gypsum products have been built into a structure, it is the dust concentrations that can occur when the building products are drilled, cut or sawed that are the determinant health factor. Experimental dust measurements have been performed to determine the dust concentrations occurring under normal conditions [27] and in exceptional circumstances.

The disposal environment (landfills)

Knowledge of the component substances present in the gypsum does not in itself permit conclusions to be drawn as to the extent to which these components will be leached out by environmental influences, pass unchanged through the soil, and find their way into the groundwater. For this reason, the health assessment must be based on such related parameters as are available for comparison, e.g. existing statutory limits for concentrations in the soil [15] or concentrations that are known and accepted as tolerable in cultivated soils [16].

4 The investigations

4.1 Selection of the samples and sampling

The study was intended to yield the broadest possible overview of the parameters on which to base an assessment of the health impact of the natural and FGD gypsums available and commer-cially marketable at the time the study was commissioned. With a view to achieving this aim, the sampling locations and conditions were selected to ensure that the gypsum samples taken were representative in terms of their geological and chemical origin and other relevant circumstances. Furthermore, gypsum boards made of calcined natural gypsum and FGD gypsum were included in the study for the analyses for dioxins and furanes.

Natural gypsum samples

Samples of natural gypsum were taken from different geological formations at 12 separate active mining locations in northern, central and southern Germany. The samples taken are representative, from both the regional and the geological points of view, of the natural gypsums processed by the gypsum industry in Germany. Specifically, the sampling locations were

— 5 deposits in younger and older Zechstein (Lower Saxony, Hesse)

— 6 deposits in Keuper (Bavaria, Baden-Wuerttemberg)

— 1 deposit in Muschelkalk (shelly marl) (Baden-Wuerttemberg).

The natural gypsum samples were taken at the minehead or in the gypsum processing works after comminution (grain size ≤ 30 mm) but before entry into the conditioning or calcinating process. For the sampling procedure, sealed polyethylene containers of 10 litre capacity with record sheets and a polyethylene shovel of 500 mℓ capacity were sent to 12 active natural gypsum mines. The samples were taken in the presence of officially appointed witnesses.

FGD gypsum samples

Samples were taken at a total of 15 coal-fired power plants (12 using hard coal, 3 burning lignite fuel). The power plants were representative of

— the entire territory of the Federal Republic of Germany, from Bavaria in the south to Lower Saxony in the north,

— all major flue gas desulphurization processes used in Germany that produce gypsum as their end product, and

— the absorbents used, i.e. limestone ($CaCO_3$) and quicklime (CaO).

The FGD gypsum samples from lignite-firing power plants came from the Rhineland lignite mining region and represent about 95 % of all FGD gypsum produced in lignite-fueled power plants in Germany.

In parallel with the FGD gypsum sample, a sample of the absorbent used for flue gas desulphurization in the same power plant was taken. The FGD gypsum samples were taken after the centrifuge or vacuum filter (depending on which was present) at the start of the settling belt over a period of about one hour of continuous production. The absorbent sample (limestone or quicklime) was taken from the on-site inventory.

Each of the 15 power plants was sent two sealed polyethylene containers of 10 litre capacity, one for the gypsum sample and one for the absorbent sample. These were accompanied by polyethylene shovels of 500 mℓ capacity as sampling tools and a specially designed sampling record sheet. The samples were taken on site in the presence of a sworn sampler or a witness appointed by the cognizant health or local authorities.

Return of the gypsum samples

The filled and sealed sample containers were returned to the Institut für Hygiene in Lübeck in the period from January to November 1988. All were accompanied by the sampling record sheets, duly filled in and signed by the person taking the sample and the officially appointed witness.

On receipt at the Institut für Hygiene in Lübeck, the gypsum samples were assigned coded laboratory numbers, with separate series for natural gypsum and FGD gypsum samples. The identity of the samples is known only to the institute.

Further to the natural gypsum and FGD gypsum samples taken, 8 mm thick calcinated natural gypsum and FGD gypsum boards (without cardboard lining) were obtained from two manufacturers for analysis for dioxin.

The measurements of gypsum dust concentration during sawing and drilling were performed on commercially available gypsum boards.

4.2 Preparation of the samples

Natural gypsum samples

All the natural gypsum samples (grain size up to 30 mm) were dried for 60 hours at 40 ± 2 °C. The individual samples weighed between 8000 and 12 000 g. After drying, the entire natural gypsum sample was ground to a grain size of below 0.2 mm in a centrifugal crusher with zirconium oxide grinding gear. Lumps were broken up by pushing through a sieve with the aid of a brush. The sieved gypsum was first mixed 20 times by coning for division into laboratory and retention specimens. The gypsum cone was then spread out over an area of about 1 m². This area was divided into 16 segments, and the contents of each segment were successively filled into the prepared specimen containers by means of a 20 mℓ polyethylene scoop.

FGD gypsum samples

All FGD gypsum samples (weighing between 8000 and 12000 g each) were dried for 60 hours at 40 ± 2 °C and then sifted through a plastic sieve with a mesh size of 0.2 mm. The subsequent worksteps were the same as for the natural gypsum samples.

Similar analysis conditions were observed for the calcinated natural gypsum and FGD gypsum boards.

4.3 Proof of homogeneity

The homogeneity of each gypsum specimen was demonstrated by means of tests performed on material from the laboratory and retention specimen containers (10 containers) using iron as indicator element.

Test for homogeneity of the gypsum specimens

The laboratory and retention specimens were tested for homogeneity in repeat determinations performed according to the following analysis procedures:

Weighed quantities of about 2 g each were mixed with 100 mℓ distilled water and 50 mℓ hydrochloric acid (concentrated superpure) and digested by heating for 15 minutes on a hotplate. After digestion, each specimen and the filtrate were topped up to 1000 mℓ with distilled water, mixed and filtered. 20 mℓ of this solution were transferred by pipette into a 100 mℓ graduated flask. 30 mℓ of 1 % sodium hydroxide, 5 mℓ ammonium acetate solution and 2 mℓ hydroxyl ammonium chloride solution were added in succession. The pH value was required to be between 3.4 and 5.5. After mixing, 2 mℓ phenanthroline solution was added and the mixture was topped up to 100 mℓ. After about 15 minutes, spectrophotometric measurement against water was performed at a wavelength of 510 nm in a 5 cm cell [7]. Homogeneity was determined statistically by means of the "F test" procedure.

Calibration

The calibration procedure was repeated before each day's analyses commenced. Standard solutions containing 0.25, 0.5, 1.0, 2.0, 4.0, 5.0 and 6.0 mg of iron per litre were prepared. 20 mℓ of each of these solutions were transferred by pipette into a 100 mℓ graduated flask, and the same volumes as above of sodium hydroxide, ammonium acetate solution, hydroxyl ammonium chloride and, after mixing, phenanthroline solution were added. After about 15 minutes, spectrophotometric measurement against water was likewise performed at a wavelength of 510 nm in a 5 cm cell. The calibration function and then the iron contents of the specimens to be analyzed were determined by computer. The homogeneity was calculated with the aid of a statistical program. Once the homogeneity of the specimens had been ascertained, the specimen containers were sealed.

4.4 Submission of the laboratory specimens

The natural gypsum and FGD gypsum specimens were sent to the following institutes for analysis:

— Institut für Hygiene der Medizinischen Universität zu Lübeck (Hygiene Institute of Lübeck Medical University) *(Professor Beckert)*,

— Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen (Hygiene and Occupational Medicine Institute, RWTH) *(Professor Einbrodt)*,

— Institut für Wasser-, Boden- und Lufthygiene des Bundes-gesundheitsamtes, Berlin (Institute for Water, Soil and Air Hygiene at the Federal Health Office, Berlin) *(Professor Fischer)*,

— Institut für Strahlenhygiene des Bundesgesundheitsamtes in Neuherberg (Institute for Radiology at the Federal Health Office, Neuherberg) (Professor Schmier),

— Institut für Wasser-, Boden- und Lufthygiene des Bundes-gesundheitsamtes in Langen (Institute for Water, Soil and Air Hygiene at the Federal Health Office, Langen) *(Dr. Christmann)*.

4.5 Trace elements

Round-robin analyses

Round-robin analyses were performed by the following institutes for the purpose of harmonizing the analysis procedures used:

— Institut für Hygiene der Medizinischen Universität zu Lübeck,

— Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen,

— Institut für Wasser-, Boden- und Lufthygiene des Bundes-gesundheitsamtes, Berlin,

— TÜV Hannover (technical inspection agency),

— VGB TECHNISCHE VEREINIGUNG DER GROSSKRAFTWERKSBETREIBER e.V. (association of large power plant operators),

— Vereinigte Elektrizitätswerke Westfalen AG, VEW (power utility),

— VEBA Kraftwerke Ruhr AG, VKR (power utility).

All participants were sent homogenized specimens. The first round-robin analysis focused on the elements arsenic, cadmium, chromium, lead, mercury and nickel. The second round-robin analysis encompassed all 16 elements to be covered by the study: arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, tellurium, thallium, vanadium and zinc.

In addition to the specimens for analysis, each laboratory was provided with one digested gypsum sample and one reagent blank. The same 16 elements were determined in this digestion. In the round-robin analysis, 4 pressure digestions were made from each specimen and 2 digestions for the reagent blanks.

Pressure digestion procedure

1 g of gypsum was weighed out on an analytical balance and transferred to the Teflon receptacle (50 mℓ) of the pressure digestion vessels, where it was mixed with 10 mℓ HNO_3 (concentrated superpure) and 1 mℓ HF (concentrated superpure) and digested for 16 hours at 180 °C. After cooling, the vessels were opened, 20 mℓ saturated boric acid solution (about 4 % superpure) added, and the vessels closed again and the contents digested for 2 hours at 120 °C. After cooling again, the contents were quantitatively transferred to a 100 mℓ silica glass graduated flask, attention being paid to ensuring that all solids (precipitates) were likewise transferred, leaving no residue behind. This suspension was placed in a drying cabinet at 80 °C until a clear solution was obtained (after about 4 hours). After cooling, the solution was topped up to 100 mℓ with demineralized water. The individual elements in this solution were then measured by means of the additive method (matrix modification) with the aid of an atomic absorption spectrometer. On conclusion of the round-robin analyses, the circle of analysts met to discuss the results obtained. After the second round of analyses the results were found to be adequately similar, so that agreement was reached on the methodology to be used for the further analyses.

Determination of the elements

Unlike in the round-robin analyses, only two digestions of each gypsum specimen were prepared. Two reagent blanks were prepared, as in the round-robin analyses. Otherwise, the analysis procedure was the same as in the round-robin analyses.

4.6 Chemical parameters

Water of crystallization

The water of crystallization content was determined by weighing out 30 to 50 g of gypsum and dehydrating it at 360 °C until the weight remained constant.

Procedure for investigating the water-soluble components

5 g of gypsum + 250 ml H_2O were boiled for about 10 minutes. The mixture was allowed to cool and then filtered, and the filter residue was washed with hot distilled water. The sodium and potassium in the filtrate were determined by flame atomic absorption spectrometry. Chloride, nitrate and cyanide were determined in accordance with the standard DEV procedure [7] and the results checked by ion chromatography. The pH value of the same filtrate was also determined.

Total digestion

1 g of gypsum + 10 mℓ HCl (concentrated) were heated at 100 to 110 °C, then 50 mℓ of hot, diluted HCl (2 n) was added and the mixture boiled. While still hot, the mixture was filtered and washed five times more with 2 n HCl and then twice with hot water. The components in this digestion that had not been dissolved in the hydrochloric acid were simultaneously determined. The calcium and magnesium in the filtrate were determined by a complexometric procedure and checked by ion chromatography. The SO_4 content in the digestion was determined and the SO_3 content derived from this result. The iron was determined by means of flame atomic absorption spectrometry, NH_4 and P_2O_5 by the standard DEV procedure, and the fluoride content by ion chromatography.

Determination of sulphites (stated as SO_2)

2 to 5 g gypsum were mixed with 10 mℓ HCl (concentrated). The SO_2 was passed into a receiver with slightly alkaline water by boiling for 10 minutes. The solution was oxidized with hydrogen peroxide 30 % and boiled once before the SO_2 was determined by gravimetry in the form of SO_4.

Determination of carbonates

2 g of gypsum were put into a two-neck round-bottomed flask. H_2SO_4 was added via a dropping funnel until the CO_2 reaction was completed. Then the contents were boiled for 10 minutes. The gas was absorbed in 0.2 n sodium hydroxide and the CO_2 content determined by back titration; allowance was made for the SO_2 content by means of a calculation factor.

4.7 Radioactivity

The procedure used to determine the specific radioactivity of the natural and man-made radioactive substances was as follows.

Preparation of the specimens

The specimens to be investigated were first homogenized and then filled into a measuring vessel (of maximum volume 350 cm^3) to the height required by the calibration of the test device. The weight of the specimens was determined and the beakers hermetically sealed. Based on the assumption that the sampling procedure and/or the preparation of the specimens might have upset the radioactive equilibrium between radium 226 and its decay products, the specimens were first allowed to stand for 4 weeks to restore equilibrium.

Determination of radioactivity

Measurements were performed on the specimens for 8 hours in the low-level test facility. The test facility consisted of 2 extra-pure germanium detectors (energy range 0.01 – 3.0 MeV) which are positioned within lead chambers (walls 7 cm thick) to shield them from ambient radioactivity. The measurement data from each of the two detectors over the period of observation were stored in a multichannel analyzer. On completion of the measurements, the data were evaluated on an on-line computer. The computer accessed a nuclide library based on PTB (German federal physics authority) publication Ra-16/2, July 1986. Calibration was performed with a mixed radium 226, thorium 232 and potassium 40 preparation. The nuclides were identified

for potassium 40 via γ energy 1.460 MeV

for radium 226 via γ energies 0.609 MeV and 0.352 MeV and

for thorium 232 via γ energies 0.583 MeV, 0.338 MeV and 0.911 MeV.

If any of these γ energy levels was not identified, no activity calculation was performed.

The following further γ energies were also used in the activity calculations for radium 226 and thorium 232:

radium 226
0.186 MeV, 0.242 MeV, 0.295 MeV, 1.120 MeV and 1.764 MeV

thorium 232
0.239 MeV, 0.300 MeV, 0.795 MeV, 0.860 MeV, 0.969 MeV and 2.615 MeV.

4.8 Dioxins and furanes

An extract was made from 100 g of gypsum by boiling three times for one hour each with 300 mℓ n-hexane in reflux. 10 different ^{13}C-marked PCDD/PCDF were added to the extract, which was then concentrated by further boiling and cleaned of interfering escort components by passing through a three-stage chromatographic column system. Identification and quantifica-tion were performed by means of gas chromatography-mass spec-trometry (GC-MS). The GC-MS system HP 5890 A/HP 5970 B (carrier gas helium, delivery pressure 0.5 bar) was equipped with an on-column injector, a retention gap (2 m × 0.32 mm i.d. disact. silica gas capillary tubes), an open tubular column SP 2331 (50 m × 0.25 mm i.d. × 0.2 µm f.d.) and a silica glass transfer capillary tube (0.5 m × 0.25 mm i.d.) for direct entry into the mass spectrometer [4].

The following temperature program was used:

130 °C, 1 min; 30 °C/min; 200 °C; 4 °C/min; 240 °C, 52 min; 5 °C/min; 250 °C, 33 min. The electrical energy was 70 eV, the transfer capillary temperature 280 °C. Two characteristic ions (M^+, $M{+}2^+$, $M{+}4^+$ at dwell times of 40, 50 and 100 ms) were used by means of the SIM mode.

The quantitative determination was performed internally via the admixed ^{13}C standards subject to the condition that within the homologous group the sensitivity to the isomers is identical. The reproduction rate was 85–102 %.

The limits of quantification were set at 0.3 to 8 ng/kg (15 ng/kg for OCDF only), depending on the chlorination level and structure (Kongener). These limits were chosen in the light of the usual dioxin and furane contents in our normal environment including the atmospheric air [22]. Neither dioxins nor furanes were detected above these limits. Subsequent investigations performed on gypsum specimens have shown that dioxins and furanes can be detected if the limits of quantification are lowered. At such low concentrations, which are lower than the known concentration levels in cultivated soils and the atmospheric air, the origin of the dioxins and furanes cannot be positively identified. The defined limits of quantification at 0.3 to 8 ng/kg are appropriate for assessment of the health impact of the gypsums studied.

4.9 Polycyclic aromatic hydrocarbons

An extract was made from 100 g of gypsum in 100 mℓ of cyclohexane in a one-hour ultrasonic bath. The cyclohexane was decanted and extraction repeated. The combined cyclohexane phases were dried in a rotary evaporator. The residue was absorbed in 5 mℓ isopropanol. The quantitative determination was performed by means of high-pressure liquid chromatography (HPLC). 20 µℓ of the isopropanol mixture were used for the analysis.

HPLC conditions:

— wavelengths: emission: 460 nm
excitation: 360 nm

— eluate: 80/20 v./v., acetonitrile/water, 1 mℓ/min

— column: HCODS, C 18.5 µ,125 mm × 4.6 mm, Perkin Elmer

4.10 Maximum dust concentration during sawing and drilling of gypsum products for the construction industry

To measure the maximum possible gypsum dust concentration that could occur under exceptional circumstances in the application environment, the following operations were performed in about half an hour of net working time on 8 mm thick gypsum boards:

— 20 simple drilled holes,

— 5 cut-outs for power sockets, and

— 34 cuts of length 60 cm, in total about 20 m.

5 Results of the investigations

The results of the investigations and analyses performed are presented in table form. The following abbreviations are used in the tables:

Gn/88/N	natural gypsum specimens
Gn/88/R	FGD gypsum specimens from hard-coal-fired power plants
Gn/88/R/B	FGD gypsum specimens from lignite-fired power plants
M1	mixed natural gypsum specimen
M2	mixed FGD gypsum specimen from hard-coal-fired power plants
M3	mixed FGD gypsum specimen from lignite-fired power plants
GP1	gypsum board made from calcinated natural gypsum
GP2/3	gypsum board made from calcinated FGD gypsum
n.d.	not detectable (below the limit of quantification)
n.p.	not performed
insol.	insoluble
w-s.	water-soluble
tot.	total
mg	milligram = 1/1000 gram
µg	microgram = 1/1000 milligram
ng	nanogram = 1/1000 microgram
Σ	sum

5.1 Homogeneity of gypsum specimens Indicator element: iron

The homogeneity of the gypsum specimens was demonstrated with the aid of iron as indicator element as described in 4.3 and listed in Table 1.

Table 1. Homogeneity of the natural gypsum and FGD gypsum specimens.

Natural gypsum	$\bar{x}$ of all measurements in mg/kg	Rel. standard deviation in %	"F" value*
G 1/88/N	11428	2.7	1.2
G 2/88/N	2589	1.9	1.57
G 3/33/N	309	2.2	1.36
G 7/88/N	2750	1.0	0.77
G 8/88/N	49	12.7	0.96
G 15/88/N	247	4.3	1.06
G 16/88/N	1128	2.3	1.46
G 17/88/N	3844	2.7	1.72
G 18/88/N	8544	3.1	1.52
G 19/88/N	412	4.7	2.48
G 20/88/N	216	5.6	1.55
G 21/88/N	3834	4.2	1.46
FGD gypsum			
G 4/88/R	2	3.8	1.57
G 5/88/R	1028	2.8	0.93
G 6/88/R	194	3.0	0.9
G 9/88/R	432	2.5	2.79
G 10/88/R	1720	4.1	1.29
G 11/88/R	167	2.9	2.13
G 12/88/R	1055	1.0	0.55
G 13/88/R	508	3.0	0.62
G 14/88/R	349	3.9	1.28
G 22/88/R	438	2.5	2.26
G 23/88/R	382	2.2	3.96
G 24/88/R	191	6.0	3.61
G 25/88/R/B1	2467	1.1	3.23
G 26/88/R/B2	1754	1.43	1.38
G 27/88/R/B3	1545	0.51	0.57

* Statistical homogeneity according to "F test", $F = \frac{\text{variance } S_1^2}{\text{variance } S_2^2}$

5.2 Chemical parameters

The chemical parameters listed in Table 2 were determined as described in 4.6 to characterize the materials.

Table 2. Chemical parameters of natural gypsum and FGD gypsum.

		Natural gypsum			FGD gypsum		
		range			range		
		min	max	mean	min	max	mean
pH value		6.1	8.58	7.38	6.33	8.54	7.21
Water of crystallization	%	15.21	18.68	16.51	19.83	20.88	20.32
CaO	%	30.80	44.41	35.82	31.03	32.06	31.68
SO_3	%	34.92	42.17	37.75	43.95	45.57	44.96
($CaSO_4 \cdot 2H_2O$) from SO_3	%	75.07	90.69	81.19	94.52	98.00	96.72
($CaSO_4 \cdot 2H_2O$) from water of crystallization	%	72.68	89.27	78.62	94.75	99.76	97.07
MgO tot.	%	0.01	0.10	0.06	0.01	0.1	0.03
Na_2O w-s.	%	0.007	0.056	0.034	0.0003	0.081	0.032
K_2O w-s.	%	0.002	0.014	0.006	< 0.00001	0.017	0.007
Fe_2O_3 tot.	%	0.02	0.55	0.19	0.0003	0.40	0.12
HCl insol.	%	0.15	0.33	0.20	0.11	0.98	0.35
NH_4	%	0.0003	0.008	0.003	0.0003	0.009	0.003
SO_2	%	0.01	0.05	0.02	0.01	0.06	0.03
P_2O_5	%	< 0.0002	0.0006	0.0003	0.0001	0.0007	0.0003
F	%	< 0.001	0.006	0.001	< 0.001	0.007	0.002
CO_2	%	0.18	0.77	0.53	0.11	0.94	0.45
CN w-s.	mg/kg	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cl w-S. equivalent to	mg/kg mg/ℓ	11.0 1.1	288.0 28.8	72.0 7.2	21.0 2.1	213.0 21.3	73.3 7.33
NO_3 w-s. equivalent to	mg/kg mg/ℓ	13.0 1.3	60.0 6.0	32.0 3.2	7.0 0.7	429.0 42.9	89.2 8.92

5.3 Trace elements

Quantitative determination was performed as described in 4.5 for 15 trace elements in all, and the results are presented in Tables 3 and 4.

Table 3. Trace elements in natural gypsum (mg/kg).

Probe	Arsenic	Beryllium	Lead	Cadmium	Chromium	Cobalt	Copper	Mangenese
G 1/88/N	1.25	0.71	21.41	0.29	24.9	4.26	14.0	132
G 2/88/N	3.14	0.49	< 3	0.05	10.5	1.32	13.3	48.9
G 3/88/N	0.47	0.46	0.49	0.52	1.16	0.21	0.65	6.85
G 7/88/N	1.74	0.20	< 2.5	0.35	6.33	0.96	6.75	49.4
G 8/88/N	0.71	0.01	< 2.5	0.07	1.26	0.01	0.18	5.48
G 15/88/N	0.51	0.51	0.58	0.13	0.85	0.17	2.30	4.08
G 16/88/N	1.87	0.20	2.55	0.16	3.58	0.50	1.84	58.5
G 17/88/N	2.99	0.16	7.52	0.30	10.2	1.98	4.00	86.4
G 18/88/N	3.79	0.66	4.43	0.10	4.92	4.39	12.1	185
G 19/88/N	1.11	0.08	< 2.5	0.07	3.53	0.27	3.75	25.8
G 20/88/N	0.22	< 0.1	0.46	< 0.02	0.65	0.12	0.01	8.46
G 21/88/N	2.82	0.62	2.13	0.03	22.0	2.30	6.85	195

Probe	Nickel	Mercury	Selenium	Tellurium	Thallium	Vanadium	Zinc
G 1/88/N	11.4	< 0.01	0.11	< 0.1	0.20	26.4	14.7
G 2/88/N	2.10	0.01	0.18	< 0.1	0.06	8.30	4.5
G 3/88/N	0.45	< 0.03	0.09	< 0.1	< 0.05	1.31	< 3
G 7/88/N	2.60	0.02	0.09	< 0.2	0.08	6.67	31.0
G 8/88/N	0.42	< 0.006	0.05	< 0.2	< 0.05	1.64	< 3
G 15/88/N	0.40	0.03	0.06	< 0.2	0.07	2.34	< 3
G 16/88/N	2.83	0.02	0.05	< 0.2	0.08	2.41	9.0
G 17/88/N	5.80	< 0.02	0.07	< 0.2	0.15	11.3	41.0
G 18/88/N	12.2	0.08	0.04	< 0.2	0.19	22.6	17.0
G 19/88/N	1.43	0.09	n.d.	n.d.	n.d.	4.96	n.d.
G 20/88/N	0.30	0.01	< 0.46	n.d.	n.d.	0.93	2.6
G 21/88/N	13.4	0.05	n.n.	n.d.	n.d.	4.18	13.0

Table 4. Trace elements in FGD gypsum (mg/kg).

Probe	Arsenic	Beryllium	Lead	Cadmium	Chromium	Cobalt	Copper	Mangenese
G 4/88/R	1.15	0.32	22.0	0.29	4.61	1.36	8.56	39.0
G 5/88/R	1.34	0.15	8.96	0.03	3.88	0.40	5.44	36.3
G 6/88/R	0.48	0.05	0.49	0.06	1.02	0.25	1.25	3.67
G 9/88/R	0.72	0.04	< 2.5	< 0.02	9.72	0.22	1.20	9.74
G 10/88/R	1.96	0.16	2.04	0.21	1.18	2.20	5.83	196
G 11/88/R	0.67	< 0.05	3.98	0.02	1.68	0.21	1.30	9.17
G 12/88/R	1.04	0.09	< 2.5	0.03	3.32	0.27	1.90	106
G 13/88/R	1.13	< 0.1	3.10	0.02	4.30	0.24	1.65	15.8
G 14/88/R	0.21	< 0.1	1.19	0.02	3.16	0.06	2.38	28.9
G 22/88/R	2.70	0.10	12.2	< 0.02	2.31	0.17	2.30	8.30
G 23/88/R	0.49	0.65	0.27	0.01	2.18	0.09	2.37	29.0
G 24/88/R	0.42	0.03	< 2.5	0.003	1.80	0.04	3.99	2.04
G 25/88/R/B1	2.04	0.24	< 3	0.14	3.64	0.49	4.65	64.9
G 26/88/R/B2	2.20	0.42	11.1	0.15	2.75	0.53	2.38	52.7
G 27/88/R/B3	2.60	0.10	6.41	< 0.02	4.80	0.49	1.10	41.7

Probe	Nickel	Mercury	Selenium	Tellurium	Thallium	Vanadium	Zinc
G 4/88/R	5.20	1.32	8.9	< 0.3	0.42	7.70	53.2
G 5/88/R	0.85	0.66	1.03	< 0.1	0.05	3.48	22.8
G 6/88/R	0.55	0.03	2.69	< 0.1	< 0.05	1.22	< 3
G 9/88/R	2.51	0.87	2.67	< 0.2	< 0.05	2.30	< 3
G 10/88/R	12.9	1.02	13.3	< 0.2	< 0.05	5.09	22.0
G 11/88/R	0.30	0.30	0.88	< 0.2	< 0.05	1.49	< 3
G 12/88/R	1.02	0.96	6.20	< 0.2	< 0.05	4.23	7.00
G 13/88/R	1.20	0.10	15.7	< 0.2	< 0.05	2.90	3.00
G 14/88/R	1.27	0.23	1.61	< 0.2	< 0.05	3.57	< 3
G 22/88/R	1.10	0.60	1.10	n.d.	n.d.	3.30	1.70
G 23/88/R	1.36	0.33	2.27	n.d.	n.d.	2.62	4.60
G 24/88/R	0.60	0.27	n.d.	n.d.	n.d.	4.00	n.d.
G 25/88/R/B1	1.63	0.76	n.d.	n.d.	n.d.	3.55	n.d.
G 26/88/R/B2	3.12	0.66	2.30	n.d.	n.d.	3.92	43.0
G 27/88/R/B3	3.20	0.90	0.70	n.d.	n.d.	5.40	24.3

5.4 Radioactivity

The results of the determination of natural radioactive materials performed as described in 4.7 are listed in Table 5. The statistical error in the measurements is ± 10%. The detection threshold of the procedure used is 10 Bq/kg. No trace of the man-made radioactive materials cobalt 60, caesium 134 or caesium 137 could be found in any of the natural gypsum or FGD gypsum specimens.

Table 5. Natural radioactive materials.

Natural gypsum	Potassium 40 (Bq/kg)	Radium 226 (Bq/kg)	Thorium 232 (Bq/kg)
G 1/88/N	370	20	20
G 2/88/N	120	20	20
G 3/88/N	30	20	20
G 7/88/N	< 10	15	< 10
G 8/88/N	70	10	10
G 15/88/N	< 10	15	< 10
G 16/88/N	120	15	< 10
G 17/88/N	240	25	< 10
G 18/88/N	360	30	10
G 19/88/N	85	25	< 10
G 20/88/N	< 10	30	< 10
G 21/88/N	370	30	20
FGD gypsum			
G 4/88/R	80	20	20
G 5/88/R	50	20	20
G 6/88/R	30	20	20
G 9/88/R	30	20	< 10
G 10/88/R	70	20	< 10
G 11/88/R	40	25	< 10
G 12/88/R	55	10	< 10
G 13/88/R	< 10	20	< 10
G 14/88/R	60	20	< 10
G 22/88/R	60	15	< 10
G 23/88/R	< 10	20	< 10
G 24/88/R	70	20	< 10
G 25/88/R/B1	70	20	< 10
G 26/88/R/B2	60	< 10	< 10
G 27/88/R/B3	< 10	20	< 10

5.5 Dioxins and furanes

The results of the analysis for dioxins and furanes described in 4.8 are listed in Table 6. The values given in parenthesis ( ) are the limits of quantification.

Table 6. Dioxins and furanes (ng/kg).

	G 1/88/N G 2/88/N G 3/88/N	G 4/88/R G 5/88/R G 6/88/R	GP 1 GP 2 GP 3	M 1 M 2	M 3
TeCDD (2,3,7,8) Σ TeCDD	n.d. (< 1) n.d.	n.d. (< 1) n.d.	n.d. (< 0.5) n.d.	n.d. (< 0.5) n.d.	n.d. (< 0.5) n.d.
PeCDD (1,2,3,7,8) Σ PeCDD	n.d. (< 3) n.d.	n.d. (< 3) n.d.	n.d. (< 1) n.d.	n.d. (< 1) n.d.	n.d. (< 1) n.d.
HxCDD (1,2,3,4,7,8) HxCDD (1,2,3,6,7,8) HxCDD (1,2,3,7,8,9) Σ HxCDD	n.d. n.d. (< 3.5) n.d. n.d.	n.d. n.d. (< 3.5) n.d. n.d.	n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. (< 1) n.d. n.d.
HpCDD (1,2,3,4,6,7,8) Σ HpCDD	n.d. (< 8) n.d.	n.d. (< 8) n.d.	n.d. (< 3.5) n.d.	n.d. (< 3.5) n.d.	n.d. (< 3.5) n.d.
OCDD	n.d. (< 8)	n.d. (< 8)	n.d. (< 8)	n.d. (< 8)	n.d. (< 8)
TeCDF (2,3,7,8) Σ TeCDF	n.d. (< 1.5) n.d.	n.d. (< 1.5) n.d.	n.d. (< 0.3) n.d.	n.d. (< 0.3) n.d.	n.d. (< 0.3) n.d.
PeCDF (1,2,3,4,8) + (7,8) PeCDF (2,3,4,7,8) Σ PeCDF	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 0.5) n.d.	n.d. n.d. (< 0.5) n.d.	n.d. n.d. (< 0.5) n.d.
HxCDF (1,2,3,4,7,8) + (7,9) HxCDF (1,2,3,6,7,8) HxCDF (1,2,3,7,8,9) HxCDF (2,3,4,6,7,8) Σ HxCDF	n.d. n.d. n.d. (< 2.5) n.d. n.d.	n.d. n.d. n.d. (< 2.5) n.d. n.d.	n.d. n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. n.d. (< 1) n.d. n.d.
HpCDF (1,2,3,4,6,7,8) HpCDF (1,2,3,4,7,8,9) Σ HpCDF	n.d. n.d. (< 3.5) n.d.	n.d. n.d. (< 3.5) n.d.	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 2) n.d.
OCDF	n.d. (< 15)	n.d. (< 15)	n.d. (< 3)	n.d. (< 3)	n.d. (< 3)

5.6 Polycyclic aromatic hydrocarbons

The polycyclic aromatic hydrocarbons were determined as described in 4.9. The results are compiled in Table 7.

Table 7. Polycyclic aromatic hydrocarbons (PAH) (µg/kg).

Specimen	PAH 1	PAH 2	PAH 3	PAH 4	PAH 5	PAH 6	PAH Σ
G 7/88/N	5,7	0,2	n.d.	n.d.	0.1	n.d.	6.0
G 9/88/R	1.2	0.1	n.d.	n.d.	n.d.		1.3
G 11/88/R	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	0.1
G 15/88/N	1.0	n.d.	n.d.	n.d.	n.d.	n.d.	1.0
M 1	0.5	0.1	n.d.	n.d.	n.d.	n.d.	0.6
M 2	0.5	n.d.	n.d.	n.d.	n.d.	n.d.	0.5
M 3	0.2	0.1	n.d.	n.d.	n.d.	n.d.	0.3

PAH 1 = fluoranthene
PAH 2 = benzo (b) fluoranthene
PAH 3 = benzo (k) fluoranthene
PAH 4 = benzo (a) pyrene
PAH 5 = benzo (ghi) perylene
PAH 6 = indeno (1,2,3-cd) pyrene
n.d.: < 0.1 µg/kg

5.7 Maximum dust concentrations during sawing and drilling of gypsum products for the construction industry

Measurements of the dust concentrations occurring under normal conditions during the smoothing and drilling of gypsum boards yielded maximum values of 0.54 mg/m³ for drilling and 4.9 mg/m³ for smoothing/planing [27].

To take into account uncommon and even improper working conditions in do-it-yourself applications, extremely high dust concentrations were generated by large-scale sawing of gypsum boards in enclosed areas. The total dust concentration when sawing work was in progress attained 209 mg/m³, and this value was used to calculate the maximum trace element concentration in the application environment (Table 8). Table 9 shows the gypsum dust concentrations measured after the work had finished (29 mg/m³).

Because of the cumulative distribution of the dust, a factor of 0.6 was used in the calculation, i.e. 60% of the total dust concentration is taken as inhalable fine dust (Figure 1).

The quantification of the maximum trace element intake in the application environment assumed a less compact work pattern, with short interruptions to the sawing action and a net working time of about half an hour (4.10) spread over a period of one hour. To make allowance for this longer exposure time, the total dust concentration was taken as 100 mg/m³ and the inhalable fine dust fraction as 100%.

Table 8. Gypsum dust concentrations measured during sawing work on gypsum boards (about ½ hour).

µg/stage	%/stage	conc./stage µg/m³	% cum.	stage
61330	21.2	44122	21.4	1
49990	17.2	35964	38.4	2
40120	13.8	28863	52.2	3
81220	28.0	58432	80.2	4
38770	13.4	27964	93.5	5
17470	6.0	12568	99.6	6
990	0.3	712	99.9	7
130	0.0	94	99.9	8
150	0.1	108	100.0	9
Σ 290170	100	208827 (208.8 mg/m³)		

Table 9. Gypsum dust concentrations measured after sawing work on gypsum boards.

µg/stage	%/stage	conc./stage µg/m³	% cum.	stage
880	21.2	44122	21.4	1
2130	17.2	35964	38.4	2
5420	13.8	28863	52.2	3
26510	28.0	58432	80.2	4
13210	13.4	27964	93.5	5
7550	6.0	12568	99.6	6
410	0.3	712	99.9	7
150	0.0	94	99.9	8
200	0.1	108	100.0	9
Σ 56460	100	29405 (29.4 mg/m³)		

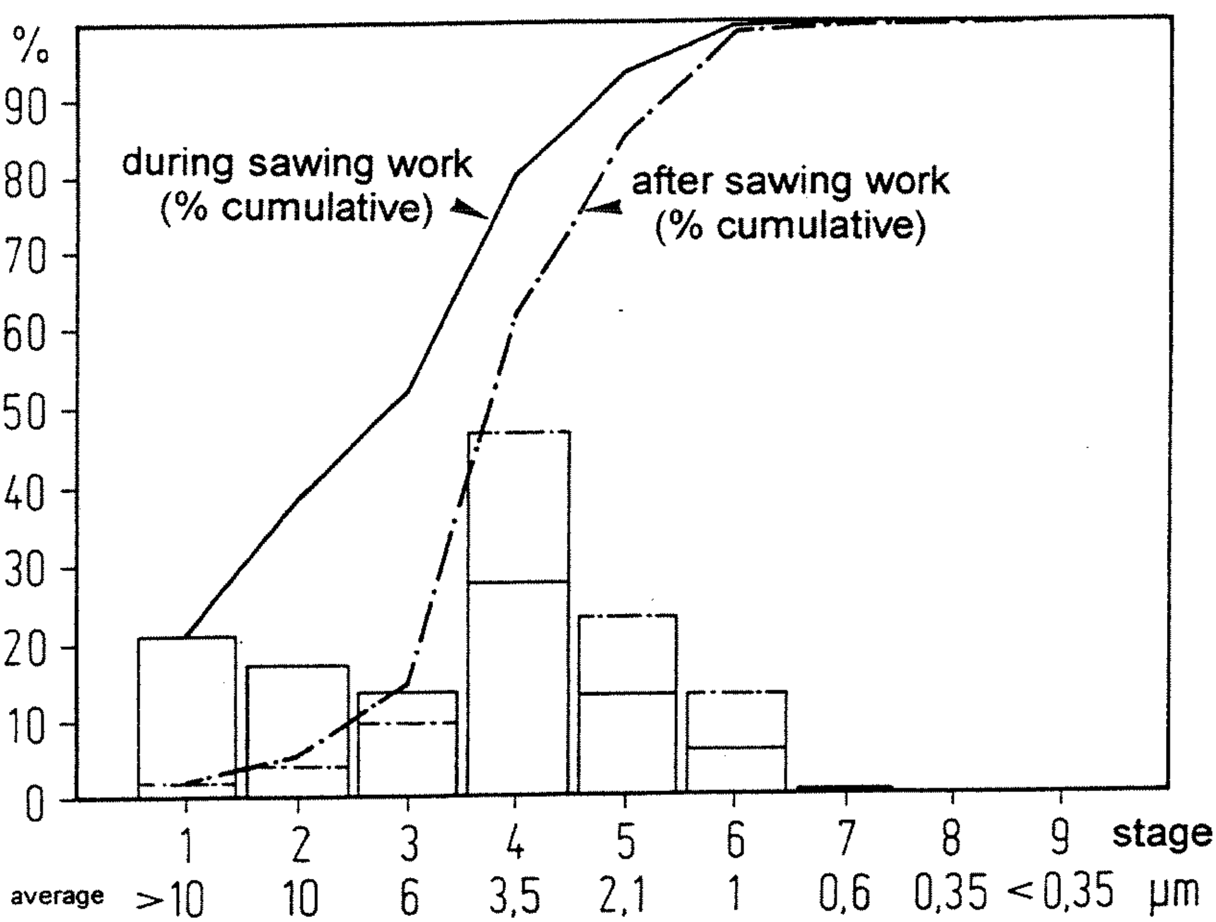


Figure 1. Percentage and cumulative distribution of gyspum dust during and after sawing of gypsum boards.

5.8 Statistical evaluation

Figure 2 compares the means and the associated percentage standard errors of the elements analyzed in the 12 natural gypsum and the 15 FGD gypsum specimens. The standard error of each mean is calculated from:

$$s_{\bar{x}} = \frac{s}{\sqrt{n}}$$

where $\bar{x}$ = mean of the analysis values
s = standard deviation
n = number of gypsum specimens.

The comparison shows that in the FGD gypsum specimens the means of all elements analyzed – except mercury and selenium – are lower than or are of a similar order of magnitude to the corresponding values in the natural gypsum specimens. The FGD gypsum contains significantly higher concentrations of mercury and selenium than does the natural gypsum. This finding is confirmed to within an error probability of < 1 % by the test for median differences.

Arsenic, lead, manganese, nickel, tellurium, thallium and zinc impurities are present in comparable orders of magnitude in both forms of gypsum, while the natural gypsums tend to exhibit higher concentrations of the elements chromium, cobalt, copper and vanadium. The beryllium and cadmium contents are significantly higher in the natural gypsum specimens.

6 Assessment of the effects of the various components of gypsum on human health

6.1 Basic considerations

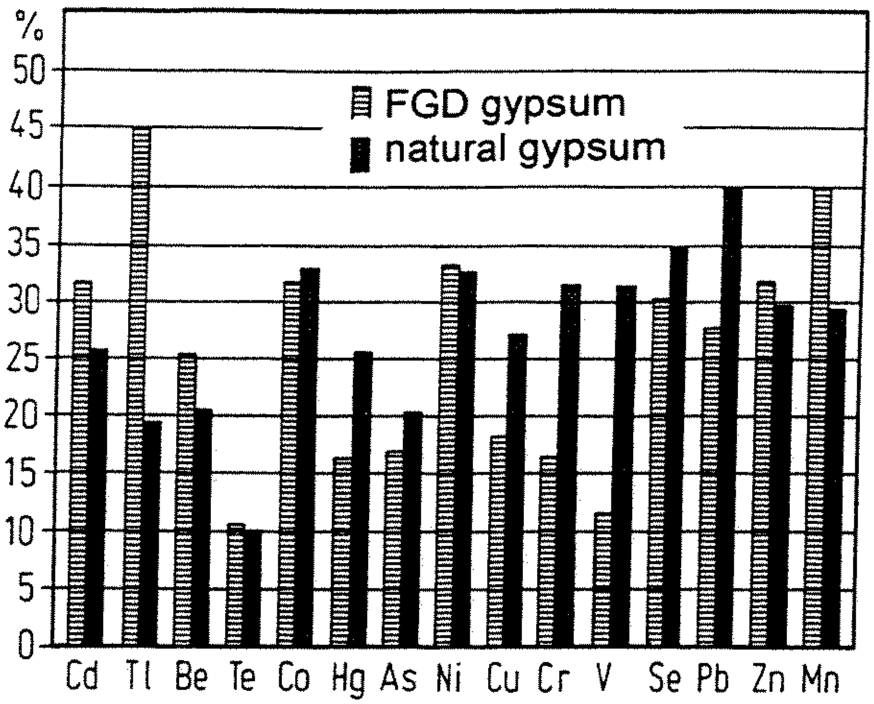
The yardsticks used in assessing the health impact of the substances contained in gypsum are the applicable statutory limits and standards and a comparison with the concentration of those substances occurring in the natural environment. The assessment takes into account the various fields of activity in which gypsum and gypsum-based building materials are encountered.

The production and processing environments

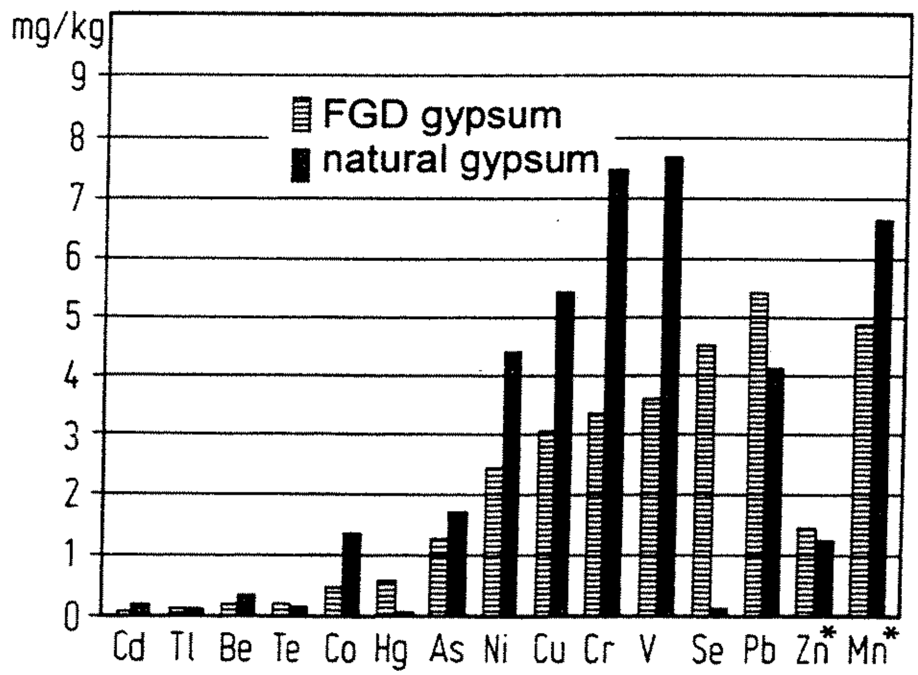
The standards adopted for assessment of the potential health hazard involved in the production and processing of gypsum and gypsum-based building materials are the maximum workplace concentration (MAK) and the technological concentration guidelines (TRK) issued by the Deutsche Forschungsgemeinschaft (German research association) commission for the review of hazardous substances at the workplace [8]. The MAK is the maximum allowable concentration, in the form of gas, vapour or airborne suspension, of any substance on or with which work is being performed at the workplace, which to the best of modern knowledge will not impair the health of or cause undue discomfort to persons repeatedly or continuously exposed to that substance for as a rule 8 hours at a time over a working week of on average 40 hours.

Since certain carcinogenic substances are unavoidable in a given technological application and may even occur in nature, certain reference standards are necessary to allow practical occupational safety measures

Standard error (% of mean)



Means $\bar{x}$ from gypsum specimens



* $\times 10^{-1}$

Figure 2. Comparison of the means $\bar{x}$ of 12 natural gypsum specimens and 15 FGD gypsum specimens versus the associated standard errors $s_{\bar{x}}$.

to be effected in the form of monitoring of workplace conditions and definition of suitable protective actions. This is the purpose of the technological concentration guidelines (TRK). The TRK value for any hazardous substance at the workplace is thus that concentration, in the form of gas, vapour or airborne suspension, which can be achieved under state-of-the-art workplace conditions and which serves as a reference standard for the protective actions to be taken and the technological monitoring to be performed at the workplace. TRK values are issued only for hazardous substances for which no MAK values can yet be defined. Observance of the technological concentration guidelines at the workplace is intended to reduce the health hazard but cannot eliminate it completely [8].

The application environment

In the application environment, where the gypsum-based building materials are used in practice, the assessment of the health impact of the potentially hazardous substances must take into account a completely different section of the population exposed to those substances under completely different conditions than those pertaining at a workplace in the production or processing environment. In the application environment, allowance must also be made for elderly and infirm persons and for children, whose resistance to those substances may be weaker than that of a healthy worker. Also, exposure may continue around the clock and possibly over a long period in a person's lifetime. For this reason, the MAK and TRK concentration values applicable to workplace conditions are not necessarily suitable as standards in the application environment. While the MAK and TRK values are based on sound scientific foundations, the basis for defining suitable thresholds for the application environment is still extremely deficient.

The potentially hazardous substances identified in the gypsum specimens are in the main non-volatile heavy metals. Nor do the finished and processed gypsum products release any dust into enclosed areas. Consequently, hazardous component substances can find their way into the air in enclosed areas only if the gypsum products are machined or drilled or, in a worst-case situation, sawn in an inexpert fashion. The study investigated even this worst case. The findings are described and discussed in the following.

The present assessment of the health impact of gypsum dust generated by working with gypsum in the application environment and the associated intake of carcinogenic trace elements is based essentially on comparisons with the amounts of pollutants which we absorb from other sources in our natural environment. The reference parameters are, in particular, the concentrations of the respective pollutants normally to be found in atmospheric air in clean-air regions. However, these comparisons are to be seen against the background of the fact that exposures to pollutants from gypsum dust are usually sporadic and of short duration only. By contrast, the intake of pollutants from the natural environment is as a rule the result of continuous exposure. This difference must be taken into account particularly in the case of the carcinogenic heavy metals, as the health risk is proportional to the product of the concentration of the carcinogenic substance and the duration of the exposure.

The disposal environment (landfills)

The analyses performed to determine the heavy metal content in the gypsum specimens related not to the elutable fractions but to the total content of these substances. For this reason, the standards used for assessing the impact of the various gypsum components are the existing statutory limits for concentrations in the soil [15] and the trace element concentrations commonly found and accepted as tolerable in cultivated soils [16]. Since the health impact of gypsum components in a landfill can be assessed only indirectly via the extent to which they pollute the drinking water, this assessment is performed at the end of this chapter, separately from the assessments for the individual components.

6.2 Terms of reference

The following assessments of the effects of the individual components of gypsum on human health are based on the results of the analyses performed and, in the case of gypsum dust at the workplace, on the findings of investigations performed and published elsewhere [27].

6.3 Gypsum dusts

The statutory dust limit of 6 mg of fine dust per m^3 air [8] is taken as the maximum exposure concentration of gypsum dusts during an 8-hour working day in a production and processing environment. The purpose of this statutory dust limit is to ensure that the proper functioning of the respiratory organs is not impaired by exposure to ordinary dust. However, even if the statutory dust limit is properly observed, a health hazard cannot be positively ruled out unless it is known with certainty that the dust can have no mutagenic, carcinogenic, fibrogenic, toxic or allergenic effects.

The effects of gypsum dust on human health were first investigated at an early stage of research into pneumoconiosis. Unlike in the case of other activities involving an exposure to dust, such as mine work, the X-rays made of workers from gypsum mines and processing works revealed no evidence either of reactionless retention of dusts in the lungs or of any fibrotic reaction [20]. Both the use of improved X-ray techniques and examinations performed on the lungs of deceased gypsum workers allowed the conclusion to be drawn that inhaled gypsum dust does not produce any morbific effects on the lungs [5, 11]. Animal experiments involving long-term inhalation of gypsum and quartz demonstrated that calcium sulphate is to be regarded as an antagonist to crystalline silicon dioxide [21, 23]. The property of promoting the elimination of quartz from the lungs, the unspecific – inert – dust reaction of the gypsum, and its positive effects on (silico-)tuberculosis led to calcium sulphate dust being used as a so-called "shielding dust" to prevent silicosis. However, this therapeutic use of gypsum dust did not go unchallenged, the main arguments raised against it being the impurities contained in the gypsum, depending on its origin [6, 10, 19]. A more recent clinical study performed on gypsum mineworkers proves that it is only the silicon dioxide content that is responsible for changes to the lungs [18].

A comprehensive study to investigate the mutagenic and carcinogenic properties of calcium sulphate dust was performed at the Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen (Hygiene and Occupational Medicine Institute, RWTH) under *Professor Einbrodt* [2]. This study used FGD gypsum in dust form in animal experiments to clarify the medical aspects of a possible toxic effect on the lungs. The test animals (young female rats) were exposed to a once-only gypsum dust concentration of 25 mg in 0.5 mℓ isotonic sodium chloride solution, applied intratracheally. The animals were examined at intervals of one day, one, three, eight and eighteen months. Histological examination of the lungs revealed signs of an unspecific alveolitis. However, no evidence of granuloma development or enhanced connective tissue formation indicative of incipient pulmonary fibrosis was found in the histological specimens. Parallel chemical analysis by means of flameless atomic absorption spectrometry revealed no elevated presence of aluminium, chromium or nickel in the parenchymatous organs such as the lungs, kidneys or liver. In the early stage of the experiment a build-up of lead in the thighbone was noted, this being washed out after 18 months. The mutagenity tests to Ames made it possible to classify the applied dust as positively non-mutagenic. From these findings the conclusion can be drawn that the gypsum dust used in the experiments can be considered inert.

Like in other highly dust-generating activities, the elevated dust concentrations possible for short times during drilling and sawing of gypsum-based building materials in the application environment make it necessary to take protective actions, e.g. wearing a face mask, even if just for comfort. The dust exposure of the do-it-yourself amateur is to be considered the "worst case" scenario. The amounts of inert calcium sulphate dust that can be inhaled or ingested during the limited time period spent engaged in these activities do not constitute a health hazard.

6.4 Anions and cations

Chemical analyses were performed to determine the anion and cation contents in the gypsum specimens. These components of the gypsum can be of relevance to human health only under certain circumstances in the context of the disposal of gypsum and gypsum-based building materials in landfills. For this reason, this aspect is discussed in the section dealing with the assessment of the health impact of FGD gypsum and natural gypsum products in landfills.

6.5 Trace elements

The production and processing environments

The calculations are based on the statutory dust limit (MAK) of 6 mg/m^3. The concentrations of the individual trace elements are obtained as follows:

max. trace element concentration (µg/m^3) =
dust concentration (mg/m^3) · trace element content (mg/kg) · 10^{-3};

e.g. for arsenic (maximum arsenic content in gypsum = 4 mg/kg):
max. arsenic concentration = $6 \cdot 4 \cdot 10^{-3} = 0.024$ µg/m^3.

Table 10. Comparison of maximum trace element concentrations in gypsum dust (particles suspended in air) in production and processing environments with the maximum allowable concentration (MAK/TRK).

Element	Max. content in natural gypsum (mg/kg)	Max. content in FGD gypsum (mg/kg)	Max. concentration in gypsum dust (µg/m^3)	MAK (µg/m^3)	TRK (µg/m^3)	Max. concentration in gypsum dust corresponds to:
Arsenic	4	3	0.024		100	1/4000 TRK
Beryllium	0.7	0.6	0.004		2	1/500 TRK
Lead	21	22	0.130	100		1/800 MAK
Cadmium*	0.5	0.3	0.003	*	*	*
Chromium	25	10	0.150		100	1/700 TRK
Cobalt	4	2	0.024		100	1/4000 TRK
Copper	14	9	0.084	1000		1/12000 MAK
Manganese	130	200	1.200	500		1/400 MAK
Nickel	13	13	0.078		500	1/6000 TRK
Mercury	0.09	1.3	0.008	100		1/12000 MAK
Selenium	0.5	16	0.096	100		1/1000 MAK
Tellurium	0.2	0.3	0.002	100		1/50000 MAK
Thallium	0.2	0.4	0.002	100		1/50000 MAK
Vanadium	26	8	0.156	50		1/300 MAK
Zinc	40	50	0.300	5000		1/17000 MAK

* No MAK or TRK values have been defined for cadmium

In the production and processing environments, the maximum trace element concentrations are 1/300 to 1/50000 of the respective MAK values. Thus, there is no health hazard due to the intake of copper, lead, manganese, mercury, selenium, tellurium, thallium, vanadium and/or zinc from gypsum dust. The maximum concentrations of the substances thought to be carcinogenic were found to be between 1/500 and 1/6000 of the respective TRK values. Observance of the technological concentration guidelines at the workplace is intended to reduce the health hazard but cannot eliminate it completely. Since, however, the maximum concentrations of the trace elements arsenic, beryllium, chromium, cobalt and nickel in the gypsum dust is three to four orders of magnitude below the respective TRK values, the health risk due to intake of these elements is negligible. No TRK value has yet been defined for cadmium, which is suspected of being carcinogenic. For this reason, the concentration of cadmium in the gypsum dust was compared with the IW 1 exposure limit (0.04 µg/m^3) prescribed in the German clean air regulation (TA Luft) [26], which, however, refers not to workplace concentrations but to concentrations in the atmospheric air. The maximum cadmium concentration in the gypsum dust was only 1/10 of this exposure limit. The health risk due to intake of cadmium is thus likewise negligible (Table 10).

The application environment

The calculations for the application environment were based on the maximum gypsum dust concentration during sawing as determined in the experiments with allowance for the cumulative distribution of the dust and the working practices (5.7). However, the assessment is based not on the trace element concentrations present in the gypsum dust but on the trace element intake during a specific period of time.

The following calculations of the maximum intake of trace elements from gypsum dust are based on the assumption that sawing of gypsum boards and the associated high dust concentration, as described in the worst-case application scenario in 5.7, is a very rare working practice. Accordingly, it is assumed that this kind of work on gypsum boards will be performed twice over a period of ten years, each time involving one sawing session of 1 hour per day and an inhaled volume of 1 m^3/h.

By way of comparison, the trace element intake in clean-air regions and the pollutant intake by a worker under conditions determined by the maximum TRK or MAK concentrations over the same (10-year) period were calculated and used as the basis for the assessment.

Calculation of the volume of clean air inhaled over 10 years, based on an exposure time of 24 hours per day:

inhaled volume: $10\ m^3/24\ h \times 365 \times 10 = 3.6 \times 10^4 m^3$.

Calculation of the volume of air inhaled by a worker based on a 40-hour working week and 45 working weeks per year:

inhaled volume: $10\ m^3/8\ h$; $50\ m^3$/week;
$50\ m^3$/week $\times$ 45 weeks $= 2.25 \times 10^3\ m^3$/year
in 10 years: $2.25\ m^3 \times 103 \times 10 = 2.25 \times 10^4 m^3$

Table 11. Comparison of a maximum trace element intake from gypsum dust (particles suspended in air) in the application environment with the maximum allowable trace element intake of a worker in the production and processing environments at the maximum allowable dust concentration (MAK/TRK) and with the intake from clean air [1, 25].

Element	Max. concentration of element at 100 mg/m^3 total dust ($\mu g/m^3$)	Intake over a period of 10 years: Max. intake in an application environment (μg)	Max. intake by a worker at max. allowable dust concentration (MAK/TRK) (μg)	Intake in clean-air regions (μg)
Arsenic	0.40	0.8	2.25×10^6	365
Beryllium	0.07	0.14	4.50×10^4	*
Lead	2.17	4.34	2.25×10^6	3600
Cadmium	0.05	0.10	**	75
Chromium	2.50	5.0	2.25×10^6	< 365
Cobalt	0.40	0.8	2.25×10^6	365
Copper	1.40	2.8	2.25×10^7	3600
Manganese	20.00	40.0	1.13×10^7	*
Nickel	1.30	2.6	1.13×10^7	600
Mercury	0.13	0.26	2.25×10^6	730
Selenium	1.60	3.2	2.25×10^6	365
Tellurium	0.03	0.06	2.25×10^6	*
Thallium	0.04	0.08	2.25×10^6	*
Vanadium	2.60	5.2	1.13×10^6	*
Zinc	5.00	10.0	1.13×10^6	7300

* Insufficient data available on concentrations of this substance in clean-air regions
** No MAK or TRK values have been defined for cadmium

The intake of the potentially carcinogenic trace elements arsenic, cadmium, chromium and nickel in the application environment lie between 1/100 and 1/1000 of the intake of the same elements in clean air over the assumed period of 10 years. The intake of these elements in the application environment is five to seven orders of magnitude lower than the maximum allowable intake of trace elements at the workplace on the basis of the applicable limits and standards (MAK/TRK). Thus, there is no health hazard due to the intake of trace elements in gypsum dust in an application environment (Table 11).

6.6 Radioactivity

The highest values for radioactivity from natural radioactive substances found in any of the gypsum specimens were:

— potassium 40: 370 Bq/kg

— radium 226: 30 Bq/kg

— thorium 232: 20 Bq/kg

Radium 226 and thorium 232 are significant in terms of the exposure of the occupants to radioactivity. Potassium 40 makes only a minor contribution to the overall radioactivity. The arithmetic mean from about 1000 samples of building materials of various types yielded a radium concentration of 40 Bq/kg and a thorium concentration of 30 Bq/kg [14]. The radionuclide concentration in the natural gypsums and FGD gypsums studied was thus below the average of other building materials. This supports the conclusion that there can be no objections from the radiological point of view to the use of the gypsum-based materials studied in the construction of buildings for residential or other human occupancy purposes.

The man-made radioactive substances cobalt 60, caesium 134 and caesium 137 were not detected in any natural or FGD gypsum specimens.

6.7 Dioxins and furanes

Dioxin ranks among the most highly toxic organic compounds. For this reason, it is a basic requirement that building materials should not give rise to any dioxin exposure in enclosed areas. No dioxins or furanes were detected in any of the natural gypsum and FGD gypsum specimens analyzed, nor in any of the gypsum boards made of natural or FGD gypsum.

6.8 Polycyclic aromatic hydrocarbons

The natural gypsum and FGD gypsum specimens were also analyzed to determine their polycyclic aromatic hydrocarbon content. The most common compound posing a potential health hazard in this group is benzo(a)pyrene. The health implications of these substances derive from the fact that statistical studies have established a probable link between the occurrence of tumours in human beings and frequent contact with mixtures of polycyclic aromatic hydrocarbons in an industrial environment.

No benzo(a)pyrene was detected in any of the gypsum specimens analyzed. Thus, adverse effects on health due to the presence of benzo(a)pyrene in gypsum dust can be positively ruled out.

6.9 Disposal of natural gypsum and FGD gypsum products on landfills

For the purposes of assessing the health impact of the trace elements, in particular of the heavy metals, in gypsum and gypsum-based building materials deposited on landfills via the extent to which they can pollute groundwater and drinking water, Table 12 compares the trace element contents found in gypsum specimens with the statutory limits for allowable concentrations of those elements in the soil [15] and with the concentrations that are accepted as tolerable in cultivated soils [16].

Table 12. Comparison of the trace element concentrations in the gypsum specimens analyzed versus the statutory in-soil concentration limits and with the concentrations frequently found and accepted as tolerable i n cultivated soils.

	Total content of trace elements in gypsum specimens (mg/kg)		Total content of of trace elements in cultivated soils (mg/kg)		
Element	natural gypsum min max	FGD gypsum min max	frequent values	tolerated values	limit values
Arsenic	0.22 – 3.79	0.21 – 2.70	2 – 20	20	
Lead	0.46 – 21.40	0.27 – 22.00	0.1 – 20		100
Cadmium	0.03 – 0.30	0.003 – 0.29	0.1 – 1.0		3
Chromium	0.65 – 24.90	1.02 – 9.72	2 – 50	100	
Fluorine	10 – 60	10 – 70	50 – 200	200	
Nickel	0.3 – 13.40	0.3 – 12.90	2 – 50		50
Mercury	0.006 – 0.05	0.03 – 1.32	0.1 – 1		2

As this comparison shows, the total content of those trace elements that are significant in terms of potential effects of gypsum or gypsum products in landfills on the drinking water is considerably lower, both in natural gypsum and in FGD gypsum, than the generally accepted and tolerated concentrations of those elements in the soil. Nearly all the concentrations measured were within the ranges commonly found in cultivated soils [15, 16].

Thus, pollution of the soil, and thus potentially of the groundwater and drinking water, to above-normal levels by the trace element content, and in particular the heavy metal content, of gypsum and building rubble from products made of natural and FGD gypsum dumped on landfills can be positively ruled out.

The influence of the cations and anions in natural gypsum deposits on the groundwater is known. The major contributing factor is the sulphate, with the result that the groundwater of soils with a high calcium sulphate content may have a relatively high sulphate concentration. For the purposes of assessing drinking water quality [29], separate limits are distinguished for magnesium sulphate and sodium sulphate on the one hand and calcium sulphate on the other. Gypsum is considered unproblematic in this context, on the basis of the findings of various studies that demonstrate that sulphate concentrations of up to 1000 mg/ℓ in the drinking water produce no adverse effects even after many years [3]. For the assessment, it can thus be taken for granted that natural gypsum deposits do not constitute a threat to the drinking water.

No clear distinctions could be found between natural gypsum and FGD gypsum. In all specimens, the concentrations of elutable nitrate were below the allowable concentration of 50 mg/ℓ provided for in the German drinking water ordinance [29]. The concentrations of elutable chloride – for which the drinking water ordinance make no provision – are below the standards given in DIN 2000 (250 mg/ℓ) [9] and in the WHO Guidelines (350 mg/ℓ) [32]. Thus, from the point of view of its health impact, the FGD gypsum analyzed is just as harmless in landfills as is natural gypsum in geological deposits.

7 Conclusions and experts' opinion

7.1 The man-made radioactive substances cobalt 60, caesium 134 and caesium 137 were not detected in any of the natural gypsum or FGD gypsum specimens analyzed. The natural radioactive materials content was very low by comparison with that of other frequently used building materials. The medically significant polycyclic aromatic hydrocarbon benzo(a)pyrene was not detected in any specimen. Dioxins and furanes were not detected either in the natural gypsum specimens or in the FGD gypsum specimen. For this reason, these parameters investigated in the study are no longer considered in the following assessment.

7.2 In the production and processing environments, contact with gypsum occurs via the respiratory tract. The statutory dust limit (maximum workplace concentration, MAK) of 6 mg/m^3 was taken as the maximum exposure concentration, since the inert gypsum dust can be regarded as posing no health hazard. Quantitative analysis for trace elements, in particular heavy metals, showed that the quantities of all elements for which analysis was performed – with the exception of mercury and selenium – in the FGD gypsum specimens were below or in the same order of magnitude as their occurrence in natural gypsum. The mercury and selenium concentrations are considerably higher in the FGD gypsum than in the natural gypsum. In the cases of beryllium and cadmium, the concentrations in the natural gypsum are significantly higher than in the FGD gypsum. The concentrations of all elements are very low, lying below 1/300 of the respective MAK or below 1/500 of the respective TRK values, whichever standard was applicable in each case. Thus a health risk from the production and processing of natural gypsum and FGD gypsum can be positively ruled out.

7.3 In the application environment, where gypsum-based building materials are used in the construction of enclosed living or working areas, no gypsum dust is normally produced, so that a potential exposure can be ruled out. Only in exceptional cases, when work is performed on gypsum-based building materials, in particular by do-it-yourself amateurs, may persons be exposed to gypsum dust for short times. The gypsum dust concentrations occurring in such cases are as a rule below the statutory dust limit (MAK). The trace element concentrations occurring in the gypsum dust are, as demonstrated earlier, very low and can be considered to pose no risk, in particular in view of the short exposure times.

To take into account extraordinary circumstances, too, extremely high dust concentrations were generated such as could arise especially if gypsum boards are inexpertly sawed. These exposures are considered the "worst case" scenario for the do-it-yourself amateur. High gypsum dust concentrations, like high dust concentrations in any other activities, would make it necessary to wear a face mask, even if only for comfort reasons. However, these conditions would apply only very rarely, with the result that the trace element intake over a 10-year period would be less than 1/100 of the pollutant intake from clean air. Thus, there is no health risk in this case, either.

7.4 When gypsum products are disposed of in landfills, their trace element content does not differ significantly from the concentrations normally found in cultivated soils. The trace element concentrations in the natural gypsums and FGD gypsums analyzed are much lower than the applicable statutory limits and the values normally accepted as tolerable for cultivated soils. Otherwise, there is no significant difference in chemical composition between natural gypsum and FGD gypsum, so that the impact of gypsum or gypsum rubble disposed of in landfills on the groundwater is similar to the impact of natural gypsum deposits, deriving only from their sulphate content, which does not pose a health hazard. A further factor to note in this context is that the amounts of gypsum deposited in a landfill will as a rule be much lower than the amounts present in a natural gypsum deposit.

7.5 In **summary**, the analyses demonstrated that the differences between natural gypsum and FGD gypsum in terms of their chemical composition and trace element content are so slight as to be of no relevance to health. The results of the analyses lead to the conclusion that the natural gypsums and FGD gypsums studied can be used without reservation on health grounds in the manufacture of building materials.

Lübeck, 1990 | Aachen, 1990 | Berlin, 1990

(Professor Dr. med. J. Beckert)
Institut für Hygiene der Medizinischen Universität zu Lübeck

(Professor Dr. med. H.J. Einbrodt)
Institut für Hygiene und Arbeitsmedizin der RWTH Aachen

(Dr. phil. M. Fischer)
(Direktor und Professor am Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes Berlin

8 References

[1] Arbeitsgruppe "Krebsrisiko durch Luftverunreinigungen" des Länderausschusses für Immissionsschutz (LAI): Berichtsentwurf Beurteilungsmaßstäbe für krebserzeugende Luftverunreinigungen vom 28. Januar 1987.

[2] Bartmann, C.: Die biologische Wirkung eines Rauchgasentschwefelungsgipses nach dem Kalksteinverfahren. Diss. Aachen (1986).

[3] Borneff, J.: Hygiene, 4. Aufl. Stuttgart, New York (1982).

[4] Christmann, W., Klöppel, K.-D., Partscht, H., Rotard, W.: "Determination of PCDD, PCDF in Ambient Air". Chemosphere Vol. 19, Nos 1–6, 521–526 (1989).

[5] Cooke, M.A.: Some occupational disease hazards. The older metals and metalloids. J. Industr. News 14, 1213 (1962).

[6] Davis, S.B., Nagelschmidt, G.: A report on the absence of pneumokoniosis among workers in pure limestone. Brit. J. Industr. Med. 13, 6 (1956).

[7] Deutsches Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung. DIN 38406, Teil 1, Weinheim (1988).

[8] DFG Deutsche Forschungsgemeinschaft: Maximale Arbeitsplatzkonzentrationen und Biologische Arbeitsstofftoleranzwerte 1988. Mitteilung XXIV der Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe, Weinheim (1988).

[9] DIN 2000: Leitsätze für die Zentrale Trainkwasserversorgung Berlin (1959).

[10] Doig, A.T.: Disabling pneumoconiosis from limestone dust. Brit. J. Industr. Med. 12, 206 (1955).

[11] Forbes, J.J., Davenport, S.J., Morgis, G.G.: Review of literature on dusts. Bureau of Mines Wash. Bulletin 478, IV, 333 S. (1959).

[12] Gutberlet, H.: Schriftliche Mitteilung (1988).

[13] Hildebrand, M.: Rauchgasentschwefelung bei EVU-Kraftwerken. Energiewirtschaftliche Tagesfragen, Heft 7, 533–539 (1988).

[14] Keller, G., Schmier, H.: Messungen und Untersuchungen über die Radioaktivität von Rauchgas-Entschwefelungs-Anlagen-Gips (REA-Gips) im Vergleich zu Naturgips. Wissenschaft u. Umwelt, 4/1988, 199-201.

[15] Klärschlammverordnung vom 25. Juni 1982. BGBl. I, 734–739.

[16] Kloke, A.: Richtwerte 80. Orientierungsdaten für tolerierbare Gesamtgehalte einiger Elemente in Kulturböden. Mitteilung des Verbandes Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten (VDLUFA), Heft 1–3 (1980).

[17] Mitteilung der VGB Technischen Vereinigung der Grosskraftwerksbetreiber e.V., Essen (1989).

[18] Oakes, D., Douglas, R., Knight, K., Wusteman, M., McDonald, J.C.: Respiratory effects of prolongued exposure to gypsum dust. Am. Occup. Hyg. 26, 838-840 (1982).

[19] Raymond, V., Sivadon, A., Conil, Ph.: Les poumons des carriers et tailleurs de pierre calcaire. Arch. Mal. Prof. 13, 169–178 (1952).

[20] Riddel, G.: Clinical investigations into the effects of gypsum dust. Can. Publ. Hlth. J. 25, 147–150 (1934).

[21] Rosmanith, J. Breining, H.: Die quarzhemmende Wirkung von Naturanhydrit im Tierversuch. Wiss. Umw. (ISU), H. 2 (1988).

[22] Rotard, W.: PCDD/PCDF in Wasser/Sediment und Boden. VDI-Berichte Nr. 631 (1987).

[23] Schepers, G.W.H., Durkan, T.M., Delahunt, A.B.: Effects of inhaled commercial hydrous calcium silicat dust animal tissues. Arch. Industr. Hlth., 348–380 (1955).

[24] Schwarz, O.etzung der Umweltschutzgesetzgebung in der Bundesrepublik Deutschland durch Kraftwerksbetreiber. Sammelband VGB-Konferenz "Kraftwerk und umwelt" (1987).

[25] Schwedt, G.: Ökochemie der Metalle. Umschau, 306, 371, 444 (1984).

[26] TA Luft: Technische Anleitung zur Reinhaltung der Luft vom 27. Februar 1986. GMBl., 95.

[27] TÜV Bayern e.V.: Messung der Staubkonzentration bei der Bearbeitung von Gipskartonplatten aus REA-Gips und aus Naturgips durch Bohren und Schleifen in einem Prüfraum. München, Mai 1988.

[28] Verordnung über Großfeuerungsanlagen. 13. BImSchV, BGBl. I, 719, vom 22. Juni 1983.

[29] Verordnung über Trinkwasser und Wasser für Lebensmittelbetriebe (TrinkwV) vom 22. Mai 1986. BGBl. I 1986, 760.

[30] Volkart, K.: Bauen mit Gips, 11. Aufl., Darmstadt (1986).

[31] Volkart, K.: REA-Gips ist Calciumsulfat-Dihydrat. Bauwirtschaft 42, 636/637 (1988).

[32] WHO: Guidelines for Drinking Water Quality. World Health Organisation (1984).

[33] Wirsching, F.: Chemische Technologie, Bd. 3 (Gips). München, Wien (1983).

[34] World Mineral, Statistics 1980–1984. Keyworth, Nottinghamshire (1986).

ATTACHMENT H

COMPARISION OF NATURAL GYPSUM AND FGD GYPSUM

VGB TECHNISCHE VEREINIGUNG DER GROSSKRAFTWERKSBETREIBER E.V.

VGB
Technical Scientific Reports
"Thermal Power Plants"

Comparision of Natural Gypsum and FGD Gypsum

Studies for a comparative assessment of the health impact of natural gypsum and FGD gypsum from coal-fired power plants with a view to their use in the manufacture of building materials

– VGB-TW 707 e –

ISSN-No. 0937-0188

VGB Technical Scientific Reports "Thermal Power Plants"

Expert's Opinion Report

on

"Studies for a comparative assessment of the health impact of natural gypsum and FGD gypsum from coal-fired power plants with a view to their use in the manufacture of building materials"

(Comparison of Natural Gypsum and FGD Gypsum)

Study commissioned by

— VGB-FORSCHUNGSSTIFTUNG, Essen
(VGB research project 88)

— Bundesverband der Gips- und Gipsbauplattenindustrie e.V., Darmstadt

Report prepared by

— **Professor Dr. med. J. Beckert,** Institut für Hygiene der Medizinischen Universität zu Lübeck (Hygiene Institute of Lübeck Medical University) (project coordinator)

— **Professor Dr. med. H.J. Einbrodt,** Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen (Hygiene and Occupational Medicine Institute, RWTH)

— **Dr. phil. M. Fischer,** Director and Professor at the Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes, Berlin (Institute for Water, Soil and Air Hygiene at the Federal Health Office, Berlin)

– VGB-TW 707 e –

Published by
VGB TECHNISCHE VEREINIGUNG
DER GROSSKRAFTWERKSBETREIBER E.V.

Obtainable from:

VGB-KRAFTWERKSTECHNIK GmbH
— Verlag technisch-wissenschaftlicher Schriften —
P.O. Box 10 39 32, D-45039 Essen

Contents

1 Topic of investigation

Samples of natural gypsum and gypsum obtained from the desulphurization of flue gases in coal-fired power plants (FGD gypsum) are to be analyzed as the basis for a comprehensive assessment of the health impact of gypsum when used as an input material for the manufacture of building materials. Particular attention is to be dedicated to investigating whether there is any difference in terms of health impact between natural gypsum and FGD gypsum.

2 Basic considerations

2.1 Building materials

The practice of classifying building materials according to whether they are of natural or synthetic origin is unsuitable as a criterion for assessing their potential impact on human health. The crucial factor determining the health impact of building materials is the substances present as constituents in the input materials and how those substances may affect the human organism. Of particular importance in this context are the concentration in which the substances act upon the organism and the duration of exposure. In the holistic consideration required of such studies today, four levels can be distinguished for the purposes of assessing the health impact of the substances in question. These four assessment levels refer to the following exposure environments:

— **production**, in which the building material is manufactured,

— **processing**, especially on the construction site,

— **application**, in which the building material is used in the construction of enclosed living or working areas, and

— **disposal**, in which the building materials remaining after demolition of a structure are consigned to ultimate storage as building rubble (dumping) or are utilized (e.g. by thermal waste incineration).

This holistic consideration calls for an exhaustive analysis of all the component substances that are present in the building materials and that may be of relevance to human health, and for studies to determine the concentrations of these substances which could affect the skin, the respiratory or the digestive tract of the human organism.

2.2 Gypsum-based building materials

Gypsum – dihydrous calcium sulphate ($CaSO_4 \cdot 2H_2O$) – is one of the oldest raw materials used in the manufacture of building materials. Gypsum occurs extensively in mineral form in the crust of the earth. This form is known as natural gypsum. However, gypsum is also obtained as a by-product of certain chemical and technological processes. A particularly prominent example of this type is the gypsum formed in the flue gas desulphurization facilities of coal-fired power plants, known for this reason as FGD gypsum.

When dihydrous calcium sulphate, also known as crude gypsum, is exposed to certain thermal processes, calcium sulphate phases with little or no water of crystallization are formed, and these later combine with free water to form again dihydrated set gypsum. These processes, known as dehydration and rehydration, form the basis of gypsum technology; they are indispensable to the use of gypsum in the production of building materials, whether in the form of wallboards or plasters [30, 33].

Gypsum-based building materials were already in use in classical times, and large-scale use of gypsum epitomized the baroque and rococo periods. Since the 19th century, the demand for gypsum has been on the rise in many parts of the globe, world-wide consumption attaining about 78 million tonnes per year (1984 data) [34]. In Germany, nearly 3 million tonnes of raw gypsum was used in the manufacture of building materials in 1987, about 2.5 million tonnes of that figure processed by the gypsum industry and 0.5 million tonnes by the cement industry [31].

Natural gypsum

Natural gypsum deposits occur in many parts of the world, having been formed in early geological ages as sedimentary rock left behind by the evaporation of ocean brine. In line with their marine origins, natural gypsums also contain small quantities of those substances that are normally present in solution in seawater. Centuries of experience have shown that natural gypsum is a versatile and unproblematic raw material that can be used to manufacture building materials for finishing the interiors of residential and business premises of all kinds.

FGD gypsum

The combustion of sulphurous fossil fuels such as hard coal, lignite (and fuel oil) produces sulphur dioxide (SO_2) which, if it is not removed in a flue gas desulphurization plant, escapes into the atmosphere with the flue gases. To preserve the quality of the air and to protect man and his environment from harmful effects of SO_2 and its derivatives, the German authorities in 1983 passed the Grossfeuerungsanlagenverordnung [28], an ordinance governing combustion of fossil fuels in industrial-scale facilities, which established the legal basis making it compulsory for fossil-fueled power plants to be fitted with flue gas desulphurization (FGD) facilities. As of 30th June 1988, all industrial-scale combustion installations intended for long-term operation have been required to be equipped with flue gas desulphurization facilities that retain at least 85 %, in many cases even more, of the SO_2 entrained in their flue gases.

Of all the flue gas desulphurization processes available, limestone-based scrubbing processes have proved most popular in Germany, accounting for 87 % of the total desulphurized power plant capacity [13]. These processes use limestone ($CaCO_3$) or quicklime (CaO) to convert the sulphur dioxide present in the flue gases into gypsum ($CaSO_4 \cdot 2H_2O$). This end product of the desulphurization process is known as FGD gypsum. Currently, about 2.2 million tonnes of FGD gypsum per year are produced in hard-coal-fired power plants and about 1.1 million tonnes per annum in lignite-fired power plants [17].

The reason why the limestone-based scrubbing processes enjoy such widespread acceptance is that they afford at one and the same time a high desulphurization efficiency, a high level of reliability in operation, and as a rule also the best economic viability by comparison with other processes. Also, Germany has large deposits of high-quality limestone, which means that the input materials used in the flue gas desulphurization process are of a quality conducive to producing FGD gypsum that is suitable for use in economically meaningful applications [24].

The desulphurization process itself takes place in scrubbing towers in which the flue gases are brought into contact with an aqueous suspension containing powdered limestone or slaked quicklime as its alkaline component. The SO_2 is washed out by the water, oxidized to sulphate SO_4^{2-} in the aqueous solution, and precipitated with calcium from the limestone/quicklime into dihydrous calcium sulphate ($CaSO_4 \cdot 2H_2O$), gypsum. The gypsum crystals are separated out of the suspension as a moist, fine crystalline powder with the aid of centrifuges or filters.

In all flue gas desulphurization facilities, the solids in the flue gases (the fly ash) are separated out by means of electrostatic filters before the flue gases enter the scrubbing tower. The gases are then either passed directly to the SO_2 absorber or are first treated in a pre-scrubbing stage. In the latter case, post-scrubbing of the gypsum at the centrifuging stage can be dispensed with, otherwise it is common practice to wash out the water-soluble components – in particular chloride – during centrifuging or filtering, if the FGD gypsum is intended for commercial use.

High-purity powdered limestone or quicklime will generally produce FGD gypsum with a purity in excess of 95 %, the remaining fraction consisting almost entirely of surplus limestone and non-water-soluble inert materials. This high level of purity is assured by the process steps of electrostatic filtering and possibly pre-scrubbing of the flue gases and post-scrubbing of the gypsum in the centrifuge. The quality of the FGD gypsum is the subject of contractual agreements with the purchasers and processors to ensure that the gypsum is suitable for further processing into high-quality products for the construction materials industry [12].

3 Subjects of investigation

3.1 Analyses and quantitative determinations to be performed

It was specified that a quantitative determination should be performed for all parameters of relevance to human health and characteristic of the origin of the respective gypsum.

Chemical analyses

ammonium, calcium, carbonate, chloride, water of crystallization, cyanide, fluoride, iron, magnesium, nitrate, pH value in the suspension, phosphate, potassium, sodium, sulphate, sulphite.

Trace elements

Arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, tellurium, thallium, vanadium, zinc.

Radioactivity

Natural radioactive substances.
Man-made radioactive substances.

Dioxins and furanes

Polycyclic aromatic hydrocarbons.

3.2 Possible effects on the human organism

An analysis of the substances present does not in itself permit any assessment of their implications for human health. These will depend primarily upon how those substances act upon the human organism. The areas in which environmental factors can act upon the human organism are known as contact zones. For the purposes of assessing the potential health impact of gypsum, there are three contact zones that must be taken into account:

The skin

Gypsum can be used as a raw material or as a building material. The long history of the successful use of gypsum in medicine, e.g. to assist in the healing of broken bones, proves that detrimental effects on health due to skin contact can be ruled out.

The respiratory tract

Gypsum can affect the respiratory tract, that is to say the bronchial tubes and the pulmonary alveoli, only in the form of inhalable dust. Exposure to gypsum in this form is possible in the production environment, in the processing environment, and in the application environment when work is performed on the finished gypsum product, e.g. when drilling holes or when sawing or cutting gypsum boards, as the user of a building may occasionally have to do. However, since drilling and sawing of gypsum boards is not common practice at the application end, users will be exposed to gypsum powder only by way of rare exceptions.

The digestive tract

Contact with gypsum and its component substances in the digestive tract may come about if inhaled gypsum particles are swallowed in the saliva and especially if they find their way into the drinking water. However, the latter is possible only if the soluble components of gypsum deposited in a landfill find their way unchanged through the soil and into the groundwater, which is then used as drinking water.

3.3 Quantification of exposure to gypsum and its active components

An assessment of the health impact of gypsum must focus on the concentrations of the gypsum component substances to which the organism is exposed in the various environments in which it may come into contact with gypsum.

The production and processing environments

The gypsum concentrations occurring here relate to the fine dust which can enter the lungs. In Germany, there is a statutory limit on the amount of airborne dust present in production and processing facilities during continuous operation. This limit is known as the maximum workplace concentration (MAK) and is set at 6mg fine dust/m^3 air [8]. If the dust concentration in any working area is higher, suitable safety measures such as the wearing of masks or the provision of forced extraction equipment must be implemented. Thus, the statutory dust limit can be taken as the highest concentration that can possibly be encountered at the workplace during continuous operation.

The application environment

Once the gypsum products have been built into a structure, it is the dust concentrations that can occur when the building products are drilled, cut or sawed that are the determinant health factor. Experimental dust measurements have been performed to determine the dust concentrations occurring under normal conditions [27] and in exceptional circumstances.

The disposal environment (landfills)

Knowledge of the component substances present in the gypsum does not in itself permit conclusions to be drawn as to the extent to which these components will be leached out by environmental influences, pass unchanged through the soil, and find their way into the groundwater. For this reason, the health assessment must be based on such related parameters as are available for comparison, e.g. existing statutory limits for concentrations in the soil [15] or concentrations that are known and accepted as tolerable in cultivated soils [16].

4 The investigations

4.1 Selection of the samples and sampling

The study was intended to yield the broadest possible overview of the parameters on which to base an assessment of the health impact of the natural and FGD gypsums available and commer-cially marketable at the time the study was commissioned. With a view to achieving this aim, the sampling locations and conditions were selected to ensure that the gypsum samples taken were representative in terms of their geological and chemical origin and other relevant circumstances. Furthermore, gypsum boards made of calcined natural gypsum and FGD gypsum were included in the study for the analyses for dioxins and furanes.

Natural gypsum samples

Samples of natural gypsum were taken from different geological formations at 12 separate active mining locations in northern, central and southern Germany. The samples taken are representative, from both the regional and the geological points of view, of the natural gypsums processed by the gypsum industry in Germany. Specifically, the sampling locations were

— 5 deposits in younger and older Zechstein (Lower Saxony, Hesse)

— 6 deposits in Keuper (Bavaria, Baden-Wuerttemberg)

— 1 deposit in Muschelkalk (shelly marl) (Baden-Wuerttemberg).

The natural gypsum samples were taken at the minehead or in the gypsum processing works after comminution (grain size ≤ 30 mm) but before entry into the conditioning or calcinating process. For the sampling procedure, sealed polyethylene containers of 10 litre capacity with record sheets and a polyethylene shovel of 500 mℓ capacity were sent to 12 active natural gypsum mines. The samples were taken in the presence of officially appointed witnesses.

FGD gypsum samples

Samples were taken at a total of 15 coal-fired power plants (12 using hard coal, 3 burning lignite fuel). The power plants were representative of

— the entire territory of the Federal Republic of Germany, from Bavaria in the south to Lower Saxony in the north,

— all major flue gas desulphurization processes used in Germany that produce gypsum as their end product, and

— the absorbents used, i.e. limestone ($CaCO_3$) and quicklime (CaO).

The FGD gypsum samples from lignite-firing power plants came from the Rhineland lignite mining region and represent about 95 % of all FGD gypsum produced in lignite-fueled power plants in Germany.

In parallel with the FGD gypsum sample, a sample of the absorbent used for flue gas desulphurization in the same power plant was taken. The FGD gypsum samples were taken after the centrifuge or vacuum filter (depending on which was present) at the start of the settling belt over a period of about one hour of continuous production. The absorbent sample (limestone or quicklime) was taken from the on-site inventory.

Each of the 15 power plants was sent two sealed polyethylene containers of 10 litre capacity, one for the gypsum sample and one for the absorbent sample. These were accompanied by polyethylene shovels of 500 mℓ capacity as sampling tools and a specially designed sampling record sheet. The samples were taken on site in the presence of a sworn sampler or a witness appointed by the cognizant health or local authorities.

Return of the gypsum samples

The filled and sealed sample containers were returned to the Institut für Hygiene in Lübeck in the period from January to November 1988. All were accompanied by the sampling record sheets, duly filled in and signed by the person taking the sample and the officially appointed witness.

On receipt at the Institut für Hygiene in Lübeck, the gypsum samples were assigned coded laboratory numbers, with separate series for natural gypsum and FGD gypsum samples. The identity of the samples is known only to the institute.

Further to the natural gypsum and FGD gypsum samples taken, 8 mm thick calcinated natural gypsum and FGD gypsum boards (without cardboard lining) were obtained from two manufacturers for analysis for dioxin.

The measurements of gypsum dust concentration during sawing and drilling were performed on commercially available gypsum boards.

4.2 Preparation of the samples

Natural gypsum samples

All the natural gypsum samples (grain size up to 30 mm) were dried for 60 hours at 40 ± 2 °C. The individual samples weighed between 8000 and 12 000 g. After drying, the entire natural gypsum sample was ground to a grain size of below 0.2 mm in a centrifugal crusher with zirconium oxide grinding gear. Lumps were broken up by pushing through a sieve with the aid of a brush. The sieved gypsum was first mixed 20 times by coning for division into laboratory and retention specimens. The gypsum cone was then spread out over an area of about 1 m^2. This area was divided into 16 segments, and the contents of each segment were successively filled into the prepared specimen containers by means of a 20 mℓ polyethylene scoop.

FGD gypsum samples

All FGD gypsum samples (weighing between 8000 and 12000 g each) were dried for 60 hours at 40 ± 2 °C and then sifted through a plastic sieve with a mesh size of 0.2 mm. The subsequent worksteps were the same as for the natural gypsum samples.

Similar analysis conditions were observed for the calcinated natural gypsum and FGD gypsum boards.

4.3 Proof of homogeneity

The homogeneity of each gypsum specimen was demonstrated by means of tests performed on material from the laboratory and retention specimen containers (10 containers) using iron as indicator element.

Test for homogeneity of the gypsum specimens

The laboratory and retention specimens were tested for homogeneity in repeat determinations performed according to the following analysis procedures:

Weighed quantities of about 2 g each were mixed with 100 mℓ distilled water and 50 mℓ hydrochloric acid (concentrated superpure) and digested by heating for 15 minutes on a hotplate. After digestion, each specimen and the filtrate were topped up to 1000 mℓ with distilled water, mixed and filtered. 20 mℓ of this solution were transferred by pipette into a 100 mℓ graduated flask. 30 mℓ of 1 % sodium hydroxide, 5 mℓ ammonium acetate solution and 2 mℓ hydroxyl ammonium chloride solution were added in succession. The pH value was required to be between 3.4 and 5.5. After mixing, 2 mℓ phenanthroline solution was added and the mixture was topped up to 100 mℓ. After about 15 minutes, spectrophotometric measurement against water was performed at a wavelength of 510 nm in a 5 cm cell [7]. Homogeneity was determined statistically by means of the "F test" procedure.

Calibration

The calibration procedure was repeated before each day's analyses commenced. Standard solutions containing 0.25, 0.5, 1.0, 2.0, 4.0, 5.0 and 6.0 mg of iron per litre were prepared. 20 mℓ of each of these solutions were transferred by pipette into a 100 mℓ graduated flask, and the same volumes as above of sodium hydroxide, ammonium acetate solution, hydroxyl ammonium chloride and, after mixing, phenanthroline solution were added. After about 15 minutes, spectrophotometric measurement against water was likewise performed at a wavelength of 510 nm in a 5 cm cell. The calibration function and then the iron contents of the specimens to be analyzed were determined by computer. The homogeneity was calculated with the aid of a statistical program. Once the homogeneity of the specimens had been ascertained, the specimen containers were sealed.

4.4 Submission of the laboratory specimens

The natural gypsum and FGD gypsum specimens were sent to the following institutes for analysis:

— Institut für Hygiene der Medizinischen Universität zu Lübeck (Hygiene Institute of Lübeck Medical University) *(Professor Beckert)*,

— Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen (Hygiene and Occupational Medicine Institute, RWTH) *(Professor Einbrodt)*,

— Institut für Wasser-, Boden- und Lufthygiene des Bundes-gesundheitsamtes, Berlin (Institute for Water, Soil and Air Hygiene at the Federal Health Office, Berlin) *(Professor Fischer)*,

— Institut für Strahlenhygiene des Bundesgesundheitsamtes in Neuherberg (Institute for Radiology at the Federal Health Office, Neuherberg) (Professor Schmier),

— Institut für Wasser-, Boden- und Lufthygiene des Bundes-gesundheitsamtes in Langen (Institute for Water, Soil and Air Hygiene at the Federal Health Office, Langen) *(Dr. Christmann)*.

4.5 Trace elements

Round-robin analyses

Round-robin analyses were performed by the following institutes for the purpose of harmonizing the analysis procedures used:

— Institut für Hygiene der Medizinischen Universität zu Lübeck,

— Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen,

— Institut für Wasser-, Boden- und Lufthygiene des Bundes-gesundheitsamtes, Berlin,

— TÜV Hannover (technical inspection agency),

— VGB TECHNISCHE VEREINIGUNG DER GROSSKRAFTWERKSBETREIBER e.V. (association of large power plant operators),

— Vereinigte Elektrizitätswerke Westfalen AG, VEW (power utility),

— VEBA Kraftwerke Ruhr AG, VKR (power utility).

All participants were sent homogenized specimens. The first round-robin analysis focused on the elements arsenic, cadmium, chromium, lead, mercury and nickel. The second round-robin analysis encompassed all 16 elements to be covered by the study: arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, tellurium, thallium, vanadium and zinc.

In addition to the specimens for analysis, each laboratory was provided with one digested gypsum sample and one reagent blank. The same 16 elements were determined in this digestion. In the round-robin analysis, 4 pressure digestions were made from each specimen and 2 digestions for the reagent blanks.

Pressure digestion procedure

1 g of gypsum was weighed out on an analytical balance and transferred to the Teflon receptacle (50 mℓ) of the pressure digestion vessels, where it was mixed with 10 mℓ HNO_3 (concentrated superpure) and 1 mℓ HF (concentrated superpure) and digested for 16 hours at 180 °C. After cooling, the vessels were opened, 20 mℓ saturated boric acid solution (about 4 % superpure) added, and the vessels closed again and the contents digested for 2 hours at 120 °C. After cooling again, the contents were quantitatively transferred to a 100 mℓ silica glass graduated flask, attention being paid to ensuring that all solids (precipitates) were likewise transferred, leaving no residue behind. This suspension was placed in a drying cabinet at 80 °C until a clear solution was obtained (after about 4 hours). After cooling, the solution was topped up to 100 mℓ with demineralized water. The individual elements in this solution were then measured by means of the additive method (matrix modification) with the aid of an atomic absorption spectrometer. On conclusion of the round-robin analyses, the circle of analysts met to discuss the results obtained. After the second round of analyses the results were found to be adequately similar, so that agreement was reached on the methodology to be used for the further analyses.

Determination of the elements

Unlike in the round-robin analyses, only two digestions of each gypsum specimen were prepared. Two reagent blanks were prepared, as in the round-robin analyses. Otherwise, the analysis procedure was the same as in the round-robin analyses.

4.6 Chemical parameters

Water of crystallization

The water of crystallization content was determined by weighing out 30 to 50 g of gypsum and dehydrating it at 360 °C until the weight remained constant.

Procedure for investigating the water-soluble components

5 g of gypsum + 250 ml H_2O were boiled for about 10 minutes. The mixture was allowed to cool and then filtered, and the filter residue was washed with hot distilled water. The sodium and potassium in the filtrate were determined by flame atomic absorption spectrometry. Chloride, nitrate and cyanide were determined in accordance with the standard DEV procedure [7] and the results checked by ion chromatography. The pH value of the same filtrate was also determined.

Total digestion

1 g of gypsum + 10 mℓ HCl (concentrated) were heated at 100 to 110 °C, then 50 mℓ of hot, diluted HCl (2 n) was added and the mixture boiled. While still hot, the mixture was filtered and washed five times more with 2 n HCl and then twice with hot water. The components in this digestion that had not been dissolved in the hydrochloric acid were simultaneously determined. The calcium and magnesium in the filtrate were determined by a complexometric procedure and checked by ion chromatography. The SO_4 content in the digestion was determined and the SO_3 content derived from this result. The iron was determined by means of flame atomic absorption spectrometry, NH_4 and P_2O_5 by the standard DEV procedure, and the fluoride content by ion chromatography.

Determination of sulphites (stated as SO_2)

2 to 5 g gypsum were mixed with 10 mℓ HCl (concentrated). The SO_2 was passed into a receiver with slightly alkaline water by boiling for 10 minutes. The solution was oxidized with hydrogen peroxide 30 % and boiled once before the SO_2 was determined by gravimetry in the form of SO_4.

Determination of carbonates

2 g of gypsum were put into a two-neck round-bottomed flask. H_2SO_4 was added via a dropping funnel until the CO_2 reaction was completed. Then the contents were boiled for 10 minutes. The gas was absorbed in 0.2 n sodium hydroxide and the CO_2 content determined by back titration; allowance was made for the SO_2 content by means of a calculation factor.

4.7 Radioactivity

The procedure used to determine the specific radioactivity of the natural and man-made radioactive substances was as follows.

Preparation of the specimens

The specimens to be investigated were first homogenized and then filled into a measuring vessel (of maximum volume 350 cm^3) to the height required by the calibration of the test device. The weight of the specimens was determined and the beakers hermetically sealed. Based on the assumption that the sampling procedure and/or the preparation of the specimens might have upset the radioactive equilibrium between radium 226 and its decay products, the specimens were first allowed to stand for 4 weeks to restore equilibrium.

Determination of radioactivity

Measurements were performed on the specimens for 8 hours in the low-level test facility. The test facility consisted of 2 extra-pure germanium detectors (energy range 0.01 – 3.0 MeV) which are positioned within lead chambers (walls 7 cm thick) to shield them from ambient radioactivity. The measurement data from each of the two detectors over the period of observation were stored in a multichannel analyzer. On completion of the measurements, the data were evaluated on an on-line computer. The computer accessed a nuclide library based on PTB (German federal physics authority) publication Ra-16/2, July 1986. Calibration was performed with a mixed radium 226, thorium 232 and potassium 40 preparation. The nuclides were identified

for potassium 40 via γ energy 1.460 MeV

for radium 226 via γ energies 0.609 MeV and 0.352 MeV and

for thorium 232 via γ energies 0.583 MeV, 0.338 MeV and 0.911 MeV.

If any of these γ energy levels was not identified, no activity calculation was performed.

The following further γ energies were also used in the activity calculations for radium 226 and thorium 232:

radium 226
0.186 MeV, 0.242 MeV, 0.295 MeV, 1.120 MeV and 1.764 MeV

thorium 232
0.239 MeV, 0.300 MeV, 0.795 MeV, 0.860 MeV, 0.969 MeV and 2.615 MeV.

4.8 Dioxins and furanes

An extract was made from 100 g of gypsum by boiling three times for one hour each with 300 mℓ n-hexane in reflux. 10 different ^{13}C-marked PCDD/PCDF were added to the extract, which was then concentrated by further boiling and cleaned of interfering escort components by passing through a three-stage chromatographic column system. Identification and quantifica-tion were performed by means of gas chromatography-mass spec-trometry (GC-MS). The GC-MS system HP 5890 A/HP 5970 B (carrier gas helium, delivery pressure 0.5 bar) was equipped with an on-column injector, a retention gap (2 m × 0.32 mm i.d. disact. silica gas capillary tubes), an open tubular column SP 2331 (50 m × 0.25 mm i.d. × 0.2 µm f.d.) and a silica glass transfer capillary tube (0.5 m × 0.25 mm i.d.) for direct entry into the mass spectrometer [4].

The following temperature program was used:

130 °C, 1 min; 30 °C/min; 200 °C; 4 °C/min; 240 °C, 52 min; 5 °C/min; 250 °C, 33 min. The electrical energy was 70 eV, the transfer capillary temperature 280 °C. Two characteristic ions (M^+, $M{+}2^+$, $M{+}4^+$ at dwell times of 40, 50 and 100 ms) were used by means of the SIM mode.

The quantitative determination was performed internally via the admixed ^{13}C standards subject to the condition that within the homologous group the sensitivity to the isomers is identical. The reproduction rate was 85–102 %.

The limits of quantification were set at 0.3 to 8 ng/kg (15 ng/kg for OCDF only), depending on the chlorination level and structure (Kongener). These limits were chosen in the light of the usual dioxin and furane contents in our normal environment including the atmospheric air [22]. Neither dioxins nor furanes were detected above these limits. Subsequent investigations performed on gypsum specimens have shown that dioxins and furanes can be detected if the limits of quantification are lowered. At such low concentrations, which are lower than the known concentration levels in cultivated soils and the atmospheric air, the origin of the dioxins and furanes cannot be positively identified. The defined limits of quantification at 0.3 to 8 ng/kg are appropriate for assessment of the health impact of the gypsums studied.

4.9 Polycyclic aromatic hydrocarbons

An extract was made from 100 g of gypsum in 100 mℓ of cyclohexane in a one-hour ultrasonic bath. The cyclohexane was decanted and extraction repeated. The combined cyclohexane phases were dried in a rotary evaporator. The residue was absorbed in 5 mℓ isopropanol. The quantitative determination was performed by means of high-pressure liquid chromatography (HPLC). 20 µℓ of the isopropanol mixture were used for the analysis.

HPLC conditions:

- wavelengths: emission: 460 nm
excitation: 360 nm
- eluate: 80/20 v./v., acetonitrile/water, 1 mℓ/min
- column: HCODS, C 18.5 µ,125 mm × 4.6 mm, Perkin Elmer

4.10 Maximum dust concentration during sawing and drilling of gypsum products for the construction industry

To measure the maximum possible gypsum dust concentration that could occur under exceptional circumstances in the application environment, the following operations were performed in about half an hour of net working time on 8 mm thick gypsum boards:

- 20 simple drilled holes,
- 5 cut-outs for power sockets, and
- 34 cuts of length 60 cm, in total about 20 m.

5 Results of the investigations

The results of the investigations and analyses performed are presented in table form. The following abbreviations are used in the tables:

Gn/88/N	natural gypsum specimens
Gn/88/R	FGD gypsum specimens from hard-coal-fired power plants
Gn/88/R/B	FGD gypsum specimens from lignite-fired power plants
M1	mixed natural gypsum specimen
M2	mixed FGD gypsum specimen from hard-coal-fired power plants
M3	mixed FGD gypsum specimen from lignite-fired power plants
GP1	gypsum board made from calcinated natural gypsum
GP2/3	gypsum board made from calcinated FGD gypsum
n.d.	not detectable (below the limit of quantification)
n.p.	not performed
insol.	insoluble
w-s.	water-soluble
tot.	total
mg	milligram = 1/1000 gram
µg	microgram = 1/1000 milligram
ng	nanogram = 1/1000 microgram
Σ	sum

5.1 Homogeneity of gypsum specimens Indicator element: iron

The homogeneity of the gypsum specimens was demonstrated with the aid of iron as indicator element as described in 4.3 and listed in Table 1.

Table 1. Homogeneity of the natural gypsum and FGD gypsum specimens.

Natural gypsum	$\bar{x}$ of all measurements in mg/kg	Rel. standard deviation in %	"F" value*
G 1/88/N	11428	2.7	1.2
G 2/88/N	2589	1.9	1.57
G 3/33/N	309	2.2	1.36
G 7/88/N	2750	1.0	0.77
G 8/88/N	49	12.7	0.96
G 15/88/N	247	4.3	1.06
G 16/88/N	1128	2.3	1.46
G 17/88/N	3844	2.7	1.72
G 18/88/N	8544	3.1	1.52
G 19/88/N	412	4.7	2.48
G 20/88/N	216	5.6	1.55
G 21/88/N	3834	4.2	1.46
FGD gypsum			
G 4/88/R	2	3.8	1.57
G 5/88/R	1028	2.8	0.93
G 6/88/R	194	3.0	0.9
G 9/88/R	432	2.5	2.79
G 10/88/R	1720	4.1	1.29
G 11/88/R	167	2.9	2.13
G 12/88/R	1055	1.0	0.55
G 13/88/R	508	3.0	0.62
G 14/88/R	349	3.9	1.28
G 22/88/R	438	2.5	2.26
G 23/88/R	382	2.2	3.96
G 24/88/R	191	6.0	3.61
G 25/88/R/B1	2467	1.1	3.23
G 26/88/R/B2	1754	1.43	1.38
G 27/88/R/B3	1545	0.51	0.57

* Statistical homogeneity according to "F test", $F = \frac{\text{variance } S_1^2}{\text{variance } S_2^2}$

5.2 Chemical parameters

The chemical parameters listed in Table 2 were determined as described in 4.6 to characterize the materials.

Table 2. Chemical parameters of natural gypsum and FGD gypsum.

		Natural gypsum			FGD gypsum		
		range			range		
		min	max	mean	min	max	mean
pH value		6.1	8.58	7.38	6.33	8.54	7.21
Water of crystallization	%	15.21	18.68	16.51	19.83	20.88	20.32
CaO	%	30.80	44.41	35.82	31.03	32.06	31.68
SO_3	%	34.92	42.17	37.75	43.95	45.57	44.96
$(CaSO_4 \cdot 2H_2O)$ from SO_3	%	75.07	90.69	81.19	94.52	98.00	96.72
$(CaSO_4 \cdot 2H_2O)$ from water of crystallization	%	72.68	89.27	78.62	94.75	99.76	97.07
MgO tot.	%	0.01	0.10	0.06	0.01	0.1	0.03
Na_2O w-s.	%	0.007	0.056	0.034	0.0003	0.081	0.032
K_2O w-s.	%	0.002	0.014	0.006	< 0.00001	0.017	0.007
Fe_2O_3 tot.	%	0.02	0.55	0.19	0.0003	0.40	0.12
HCl insol.	%	0.15	0.33	0.20	0.11	0.98	0.35
NH_4	%	0.0003	0.008	0.003	0.0003	0.009	0.003
SO_2	%	0.01	0.05	0.02	0.01	0.06	0.03
P_2O_5	%	< 0.0002	0.0006	0.0003	0.0001	0.0007	0.0003
F	%	< 0.001	0.006	0.001	< 0.001	0.007	0.002
CO_2	%	0.18	0.77	0.53	0.11	0.94	0.45
CN w-s.	mg/kg	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cl w-S. equivalent to	mg/kg mg/ℓ	11.0 1.1	288.0 28.8	72.0 7.2	21.0 2.1	213.0 21.3	73.3 7.33
NO_3 w-s. equivalent to	mg/kg mg/ℓ	13.0 1.3	60.0 6.0	32.0 3.2	7.0 0.7	429.0 42.9	89.2 8.92

5.3 Trace elements

Quantitative determination was performed as described in 4.5 for 15 trace elements in all, and the results are presented in Tables 3 and 4.

Table 3. Trace elements in natural gypsum (mg/kg).

Probe	Arsenic	Beryllium	Lead	Cadmium	Chromium	Cobalt	Copper	Mangenese
G 1/88/N	1.25	0.71	21.41	0.29	24.9	4.26	14.0	132
G 2/88/N	3.14	0.49	< 3	0.05	10.5	1.32	13.3	48.9
G 3/88/N	0.47	0.46	0.49	0.52	1.16	0.21	0.65	6.85
G 7/88/N	1.74	0.20	< 2.5	0.35	6.33	0.96	6.75	49.4
G 8/88/N	0.71	0.01	< 2.5	0.07	1.26	0.01	0.18	5.48
G 15/88/N	0.51	0.51	0.58	0.13	0.85	0.17	2.30	4.08
G 16/88/N	1.87	0.20	2.55	0.16	3.58	0.50	1.84	58.5
G 17/88/N	2.99	0.16	7.52	0.30	10.2	1.98	4.00	86.4
G 18/88/N	3.79	0.66	4.43	0.10	4.92	4.39	12.1	185
G 19/88/N	1.11	0.08	< 2.5	0.07	3.53	0.27	3.75	25.8
G 20/88/N	0.22	< 0.1	0.46	< 0.02	0.65	0.12	0.01	8.46
G 21/88/N	2.82	0.62	2.13	0.03	22.0	2.30	6.85	195

Probe	Nickel	Mercury	Selenium	Tellurium	Thallium	Vanadium	Zinc
G 1/88/N	11.4	< 0.01	0.11	< 0.1	0.20	26.4	14.7
G 2/88/N	2.10	0.01	0.18	< 0.1	0.06	8.30	4.5
G 3/88/N	0.45	< 0.03	0.09	< 0.1	< 0.05	1.31	< 3
G 7/88/N	2.60	0.02	0.09	< 0.2	0.08	6.67	31.0
G 8/88/N	0.42	< 0.006	0.05	< 0.2	< 0.05	1.64	< 3
G 15/88/N	0.40	0.03	0.06	< 0.2	0.07	2.34	< 3
G 16/88/N	2.83	0.02	0.05	< 0.2	0.08	2.41	9.0
G 17/88/N	5.80	< 0.02	0.07	< 0.2	0.15	11.3	41.0
G 18/88/N	12.2	0.08	0.04	< 0.2	0.19	22.6	17.0
G 19/88/N	1.43	0.09	n.d.	n.d.	n.d.	4.96	n.d.
G 20/88/N	0.30	0.01	< 0.46	n.d.	n.d.	0.93	2.6
G 21/88/N	13.4	0.05	n.n.	n.d.	n.d.	4.18	13.0

Table 4. Trace elements in FGD gypsum (mg/kg).

Probe	Arsenic	Beryllium	Lead	Cadmium	Chromium	Cobalt	Copper	Mangenese
G 4/88/R	1.15	0.32	22.0	0.29	4.61	1.36	8.56	39.0
G 5/88/R	1.34	0.15	8.96	0.03	3.88	0.40	5.44	36.3
G 6/88/R	0.48	0.05	0.49	0.06	1.02	0.25	1.25	3.67
G 9/88/R	0.72	0.04	< 2.5	< 0.02	9.72	0.22	1.20	9.74
G 10/88/R	1.96	0.16	2.04	0.21	1.18	2.20	5.83	196
G 11/88/R	0.67	< 0.05	3.98	0.02	1.68	0.21	1.30	9.17
G 12/88/R	1.04	0.09	< 2.5	0.03	3.32	0.27	1.90	106
G 13/88/R	1.13	< 0.1	3.10	0.02	4.30	0.24	1.65	15.8
G 14/88/R	0.21	< 0.1	1.19	0.02	3.16	0.06	2.38	28.9
G 22/88/R	2.70	0.10	12.2	< 0.02	2.31	0.17	2.30	8.30
G 23/88/R	0.49	0.65	0.27	0.01	2.18	0.09	2.37	29.0
G 24/88/R	0.42	0.03	< 2.5	0.003	1.80	0.04	3.99	2.04
G 25/88/R/B1	2.04	0.24	< 3	0.14	3.64	0.49	4.65	64.9
G 26/88/R/B2	2.20	0.42	11.1	0.15	2.75	0.53	2.38	52.7
G 27/88/R/B3	2.60	0.10	6.41	< 0.02	4.80	0.49	1.10	41.7

Probe	Nickel	Mercury	Selenium	Tellurium	Thallium	Vanadium	Zinc
G 4/88/R	5.20	1.32	8.9	< 0.3	0.42	7.70	53.2
G 5/88/R	0.85	0.66	1.03	< 0.1	0.05	3.48	22.8
G 6/88/R	0.55	0.03	2.69	< 0.1	< 0.05	1.22	< 3
G 9/88/R	2.51	0.87	2.67	< 0.2	< 0.05	2.30	< 3
G 10/88/R	12.9	1.02	13.3	< 0.2	< 0.05	5.09	22.0
G 11/88/R	0.30	0.30	0.88	< 0.2	< 0.05	1.49	< 3
G 12/88/R	1.02	0.96	6.20	< 0.2	< 0.05	4.23	7.00
G 13/88/R	1.20	0.10	15.7	< 0.2	< 0.05	2.90	3.00
G 14/88/R	1.27	0.23	1.61	< 0.2	< 0.05	3.57	< 3
G 22/88/R	1.10	0.60	1.10	n.d.	n.d.	3.30	1.70
G 23/88/R	1.36	0.33	2.27	n.d.	n.d.	2.62	4.60
G 24/88/R	0.60	0.27	n.d.	n.d.	n.d.	4.00	n.d.
G 25/88/R/B1	1.63	0.76	n.d.	n.d.	n.d.	3.55	n.d.
G 26/88/R/B2	3.12	0.66	2.30	n.d.	n.d.	3.92	43.0
G 27/88/R/B3	3.20	0.90	0.70	n.d.	n.d.	5.40	24.3

5.4 Radioactivity

The results of the determination of natural radioactive materials performed as described in 4.7 are listed in Table 5. The statistical error in the measurements is ± 10%. The detection threshold of the procedure used is 10 Bq/kg. No trace of the man-made radioactive materials cobalt 60, caesium 134 or caesium 137 could be found in any of the natural gypsum or FGD gypsum specimens.

Table 5. Natural radioactive materials.

Natural gypsum	Potassium 40 (Bq/kg)	Radium 226 (Bq/kg)	Thorium 232 (Bq/kg)
G 1/88/N	370	20	20
G 2/88/N	120	20	20
G 3/88/N	30	20	20
G 7/88/N	< 10	15	< 10
G 8/88/N	70	10	10
G 15/88/N	< 10	15	< 10
G 16/88/N	120	15	< 10
G 17/88/N	240	25	< 10
G 18/88/N	360	30	10
G 19/88/N	85	25	< 10
G 20/88/N	< 10	30	< 10
G 21/88/N	370	30	20
FGD gypsum			
G 4/88/R	80	20	20
G 5/88/R	50	20	20
G 6/88/R	30	20	20
G 9/88/R	30	20	< 10
G 10/88/R	70	20	< 10
G 11/88/R	40	25	< 10
G 12/88/R	55	10	< 10
G 13/88/R	< 10	20	< 10
G 14/88/R	60	20	< 10
G 22/88/R	60	15	< 10
G 23/88/R	< 10	20	< 10
G 24/88/R	70	20	< 10
G 25/88/R/B1	70	20	< 10
G 26/88/R/B2	60	< 10	< 10
G 27/88/R/B3	< 10	20	< 10

5.5 Dioxins and furanes

The results of the analysis for dioxins and furanes described in 4.8 are listed in Table 6. The values given in parenthesis ( ) are the limits of quantification.

Table 6. Dioxins and furanes (ng/kg).

	G 1/88/N G 2/88/N G 3/88/N	G 4/88/R G 5/88/R G 6/88/R	GP 1 GP 2 GP 3	M 1 M 2	M 3
TeCDD (2,3,7,8) Σ TeCDD	n.d. (< 1) n.d.	n.d. (< 1) n.d.	n.d. (< 0.5) n.d.	n.d. (< 0.5) n.d.	n.d. (< 0.5) n.d.
PeCDD (1,2,3,7,8) Σ PeCDD	n.d. (< 3) n.d.	n.d. (< 3) n.d.	n.d. (< 1) n.d.	n.d. (< 1) n.d.	n.d. (< 1) n.d.
HxCDD (1,2,3,4,7,8) HxCDD (1,2,3,6,7,8) HxCDD (1,2,3,7,8,9) Σ HxCDD	n.d. n.d. (< 3.5) n.d. n.d.	n.d. n.d. (< 3.5) n.d. n.d.	n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. (< 1) n.d. n.d.
HpCDD (1,2,3,4,6,7,8) Σ HpCDD	n.d. (< 8) n.d.	n.d. (< 8) n.d.	n.d. (< 3.5) n.d.	n.d. (< 3.5) n.d.	n.d. (< 3.5) n.d.
OCDD	n.d. (< 8)	n.d. (< 8)	n.d. (< 8)	n.d. (< 8)	n.d. (< 8)
TeCDF (2,3,7,8) Σ TeCDF	n.d. (< 1.5) n.d.	n.d. (< 1.5) n.d.	n.d. (< 0.3) n.d.	n.d. (< 0.3) n.d.	n.d. (< 0.3) n.d.
PeCDF (1,2,3,4,8) + (7,8) PeCDF (2,3,4,7,8) Σ PeCDF	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 0.5) n.d.	n.d. n.d. (< 0.5) n.d.	n.d. n.d. (< 0.5) n.d.
HxCDF (1,2,3,4,7,8) + (7,9) HxCDF (1,2,3,6,7,8) HxCDF (1,2,3,7,8,9) HxCDF (2,3,4,6,7,8) Σ HxCDF	n.d. n.d. n.d. (< 2.5) n.d. n.d.	n.d. n.d. n.d. (< 2.5) n.d. n.d.	n.d. n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. n.d. (< 1) n.d. n.d.	n.d. n.d. n.d. (< 1) n.d. n.d.
HpCDF (1,2,3,4,6,7,8) HpCDF (1,2,3,4,7,8,9) Σ HpCDF	n.d. n.d. (< 3.5) n.d.	n.d. n.d. (< 3.5) n.d.	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 2) n.d.	n.d. n.d. (< 2) n.d.
OCDF	n.d. (< 15)	n.d. (< 15)	n.d. (< 3)	n.d. (< 3)	n.d. (< 3)

5.6 Polycyclic aromatic hydrocarbons

The polycyclic aromatic hydrocarbons were determined as described in 4.9. The results are compiled in Table 7.

Table 7. Polycyclic aromatic hydrocarbons (PAH) (µg/kg).

Specimen	PAH 1	PAH 2	PAH 3	PAH 4	PAH 5	PAH 6	PAH Σ
G 7/88/N	5,7	0,2	n.d.	n.d.	0.1	n.d.	6.0
G 9/88/R	1.2	0.1	n.d.	n.d.	n.d.		1.3
G 11/88/R	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	0.1
G 15/88/N	1.0	n.d.	n.d.	n.d.	n.d.	n.d.	1.0
M 1	0.5	0.1	n.d.	n.d.	n.d.	n.d.	0.6
M 2	0.5	n.d.	n.d.	n.d.	n.d.	n.d.	0.5
M 3	0.2	0.1	n.d.	n.d.	n.d.	n.d.	0.3

PAH 1 = fluoranthene
PAH 2 = benzo (b) fluoranthene
PAH 3 = benzo (k) fluoranthene
PAH 4 = benzo (a) pyrene
PAH 5 = benzo (ghi) perylene
PAH 6 = indeno (1,2,3-cd) pyrene
n.d.: < 0.1 µg/kg

5.7 Maximum dust concentrations during sawing and drilling of gypsum products for the construction industry

Measurements of the dust concentrations occurring under normal conditions during the smoothing and drilling of gypsum boards yielded maximum values of 0.54 mg/m^3 for drilling and 4.9 mg/m^3 for smoothing/planing [27].

To take into account uncommon and even improper working conditions in do-it-yourself applications, extremely high dust concentrations were generated by large-scale sawing of gypsum boards in enclosed areas. The total dust concentration when sawing work was in progress attained 209 mg/m^3, and this value was used to calculate the maximum trace element concentration in the application environment (Table 8). Table 9 shows the gypsum dust concentrations measured after the work had finished (29 mg/m^3).

Because of the cumulative distribution of the dust, a factor of 0.6 was used in the calculation, i.e. 60% of the total dust concentration is taken as inhalable fine dust (Figure 1).

The quantification of the maximum trace element intake in the application environment assumed a less compact work pattern, with short interruptions to the sawing action and a net working time of about half an hour (4.10) spread over a period of one hour. To make allowance for this longer exposure time, the total dust concentration was taken as 100 mg/m^3 and the inhalable fine dust fraction as 100%.

Table 8. Gypsum dust concentrations measured during sawing work on gypsum boards (about ½ hour).

µg/stage	%/stage	conc./stage µg/m^3	% cum.	stage
61 330	21.2	44 122	21.4	1
49 990	17.2	35 964	38.4	2
40 120	13.8	28 863	52.2	3
81 220	28.0	58 432	80.2	4
38 770	13.4	27 964	93.5	5
17 470	6.0	12 568	99.6	6
990	0.3	712	99.9	7
130	0.0	94	99.9	8
150	0.1	108	100.0	9
Σ 290 170	100	208 827 (208.8 mg/m^3)		

Table 9. Gypsum dust concentrations measured after sawing work on gypsum boards.

µg/stage	%/stage	conc./stage µg/m^3	% cum.	stage
880	21.2	44 122	21.4	1
2 130	17.2	35 964	38.4	2
5 420	13.8	28 863	52.2	3
26 510	28.0	58 432	80.2	4
13 210	13.4	27 964	93.5	5
7 550	6.0	12 568	99.6	6
410	0.3	712	99.9	7
150	0.0	94	99.9	8
200	0.1	108	100.0	9
Σ 56 460	100	29 405 (29.4 mg/m^3)		

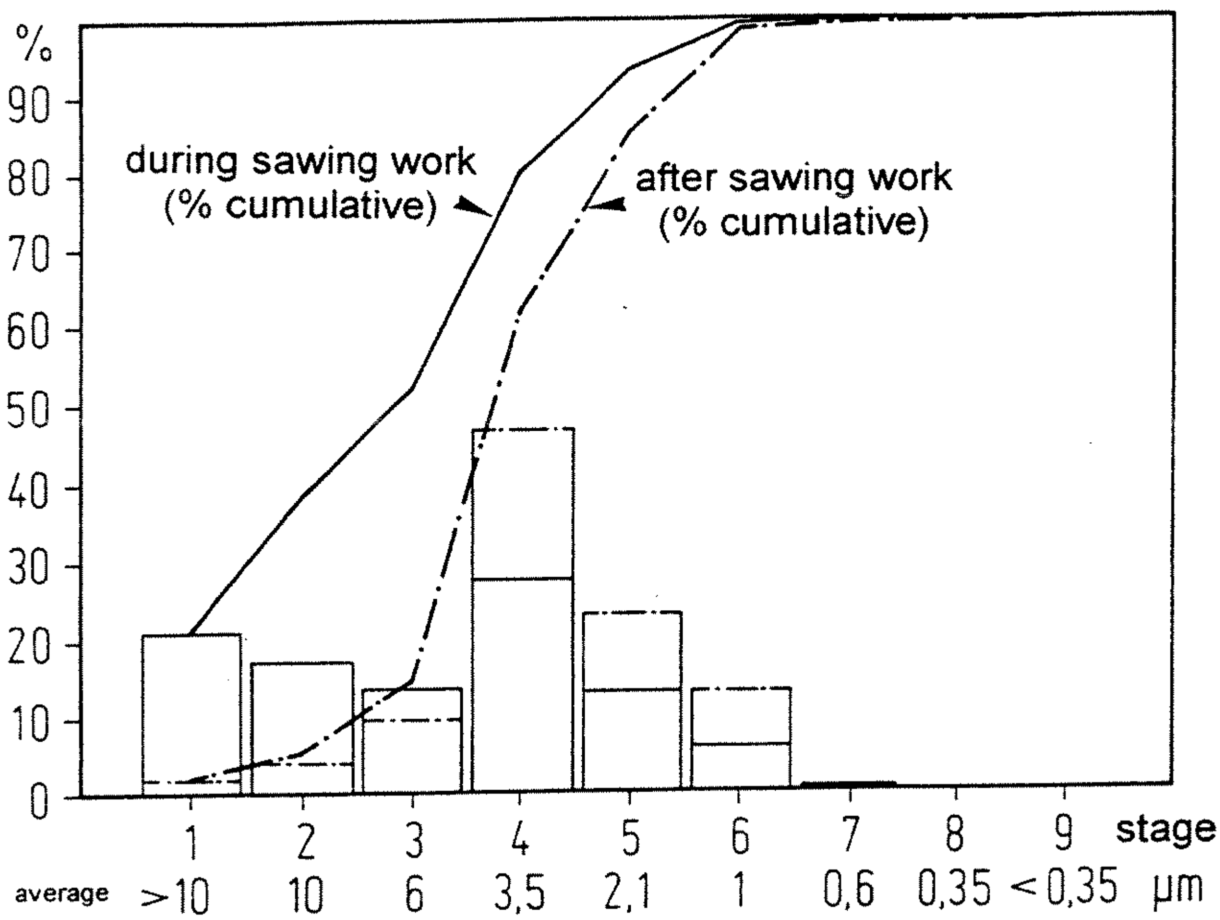


Figure 1. Percentage and cumulative distribution of gyspum dust during and after sawing of gypsum boards.

5.8 Statistical evaluation

Figure 2 compares the means and the associated percentage standard errors of the elements analyzed in the 12 natural gypsum and the 15 FGD gypsum specimens. The standard error of each mean is calculated from:

$$s_{\bar{x}} = \frac{s}{\sqrt{n}}$$

where $\bar{x}$ = mean of the analysis values
s = standard deviation
n = number of gypsum specimens.

The comparison shows that in the FGD gypsum specimens the means of all elements analyzed – except mercury and selenium – are lower than or are of a similar order of magnitude to the corresponding values in the natural gypsum specimens. The FGD gypsum contains significantly higher concentrations of mercury and selenium than does the natural gypsum. This finding is confirmed to within an error probability of < 1 % by the test for median differences.

Arsenic, lead, manganese, nickel, tellurium, thallium and zinc impurities are present in comparable orders of magnitude in both forms of gypsum, while the natural gypsums tend to exhibit higher concentrations of the elements chromium, cobalt, copper and vanadium. The beryllium and cadmium contents are significantly higher in the natural gypsum specimens.

6 Assessment of the effects of the various components of gypsum on human health

6.1 Basic considerations

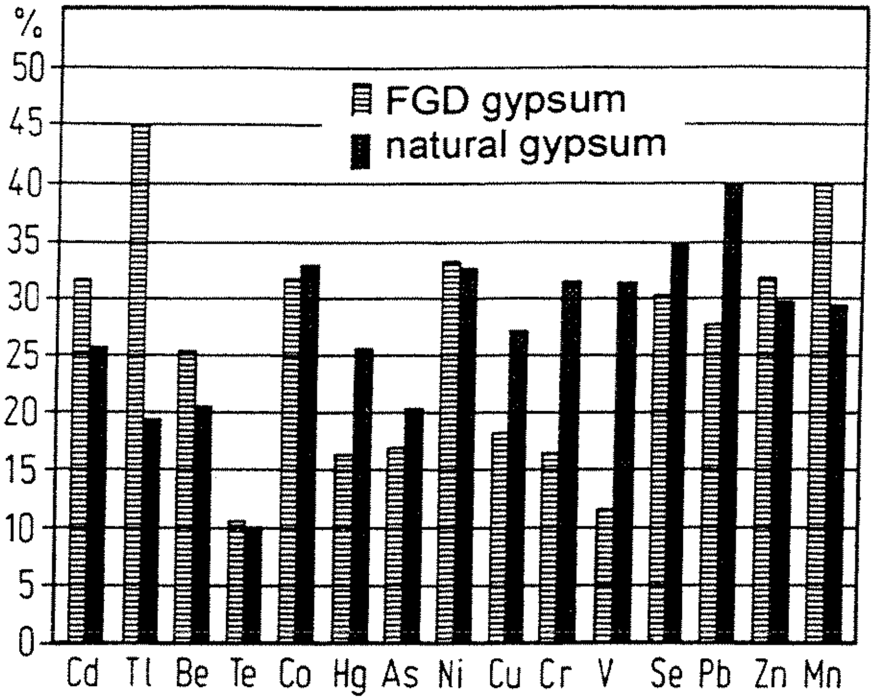
The yardsticks used in assessing the health impact of the substances contained in gypsum are the applicable statutory limits and standards and a comparison with the concentration of those substances occurring in the natural environment. The assessment takes into account the various fields of activity in which gypsum and gypsum-based building materials are encountered.

The production and processing environments

The standards adopted for assessment of the potential health hazard involved in the production and processing of gypsum and gypsum-based building materials are the maximum workplace concentration (MAK) and the technological concentration guidelines (TRK) issued by the Deutsche Forschungsgemeinschaft (German research association) commission for the review of hazardous substances at the workplace [8]. The MAK is the maximum allowable concentration, in the form of gas, vapour or airborne suspension, of any substance on or with which work is being performed at the workplace, which to the best of modern knowledge will not impair the health of or cause undue discomfort to persons repeatedly or continuously exposed to that substance for as a rule 8 hours at a time over a working week of on average 40 hours.

Since certain carcinogenic substances are unavoidable in a given technological application and may even occur in nature, certain reference standards are necessary to allow practical occupational safety measures

Standard error (% of mean)



Means $\bar{x}$ from gypsum specimens

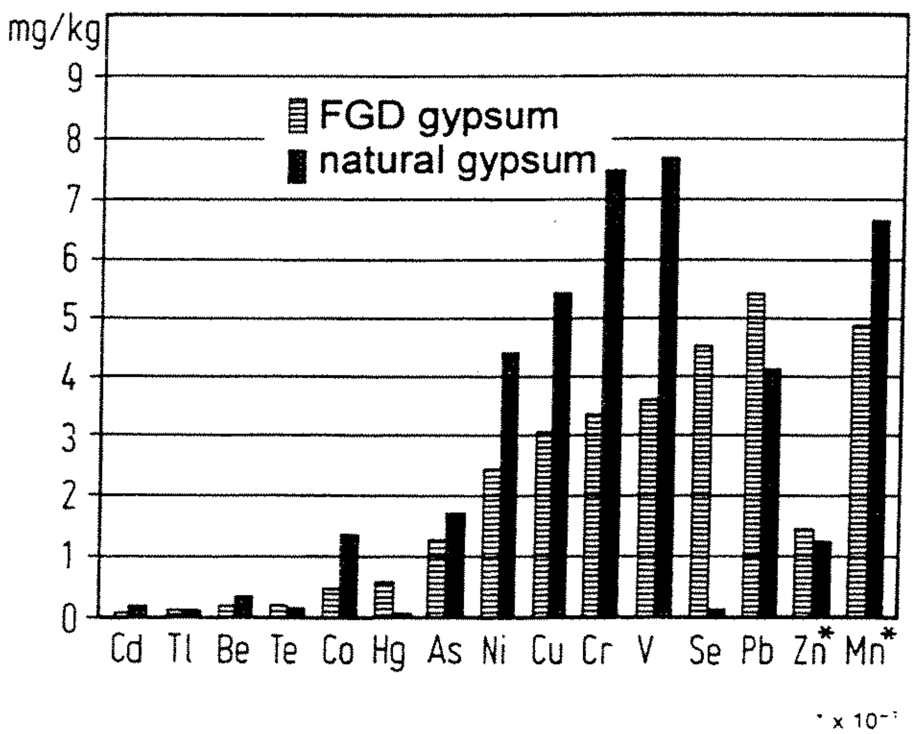


Figure 2. Comparison of the means $\bar{x}$ of 12 natural gypsum specimens and 15 FGD gypsum specimens versus the associated standard errors $s_{\bar{x}}$.

to be effected in the form of monitoring of workplace conditions and definition of suitable protective actions. This is the purpose of the technological concentration guidelines (TRK). The TRK value for any hazardous substance at the workplace is thus that concentration, in the form of gas, vapour or airborne suspension, which can be achieved under state-of-the-art workplace conditions and which serves as a reference standard for the protective actions to be taken and the technological monitoring to be performed at the workplace. TRK values are issued only for hazardous substances for which no MAK values can yet be defined. Observance of the technological concentration guidelines at the workplace is intended to reduce the health hazard but cannot eliminate it completely [8].

The application environment

In the application environment, where the gypsum-based building materials are used in practice, the assessment of the health impact of the potentially hazardous substances must take into account a completely different section of the population exposed to those substances under completely different conditions than those pertaining at a workplace in the production or processing environment. In the application environment, allowance must also be made for elderly and infirm persons and for children, whose resistance to those substances may be weaker than that of a healthy worker. Also, exposure may continue around the clock and possibly over a long period in a person's lifetime. For this reason, the MAK and TRK concentration values applicable to workplace conditions are not necessarily suitable as standards in the application environment. While the MAK and TRK values are based on sound scientific foundations, the basis for defining suitable thresholds for the application environment is still extremely deficient.

The potentially hazardous substances identified in the gypsum specimens are in the main non-volatile heavy metals. Nor do the finished and processed gypsum products release any dust into enclosed areas. Consequently, hazardous component substances can find their way into the air in enclosed areas only if the gypsum products are machined or drilled or, in a worst-case situation, sawn in an inexpert fashion. The study investigated even this worst case. The findings are described and discussed in the following.

The present assessment of the health impact of gypsum dust generated by working with gypsum in the application environment and the associated intake of carcinogenic trace elements is based essentially on comparisons with the amounts of pollutants which we absorb from other sources in our natural environment. The reference parameters are, in particular, the concentrations of the respective pollutants normally to be found in atmospheric air in clean-air regions. However, these comparisons are to be seen against the background of the fact that exposures to pollutants from gypsum dust are usually sporadic and of short duration only. By contrast, the intake of pollutants from the natural environment is as a rule the result of continuous exposure. This difference must be taken into account particularly in the case of the carcinogenic heavy metals, as the health risk is proportional to the product of the concentration of the carcinogenic substance and the duration of the exposure.

The disposal environment (landfills)

The analyses performed to determine the heavy metal content in the gypsum specimens related not to the elutable fractions but to the total content of these substances. For this reason, the standards used for assessing the impact of the various gypsum components are the existing statutory limits for concentrations in the soil [15] and the trace element concentrations commonly found and accepted as tolerable in cultivated soils [16]. Since the health impact of gypsum components in a landfill can be assessed only indirectly via the extent to which they pollute the drinking water, this assessment is performed at the end of this chapter, separately from the assessments for the individual components.

6.2 Terms of reference

The following assessments of the effects of the individual components of gypsum on human health are based on the results of the analyses performed and, in the case of gypsum dust at the workplace, on the findings of investigations performed and published elsewhere [27].

6.3 Gypsum dusts

The statutory dust limit of 6 mg of fine dust per m^3 air [8] is taken as the maximum exposure concentration of gypsum dusts during an 8-hour working day in a production and processing environment. The purpose of this statutory dust limit is to ensure that the proper functioning of the respiratory organs is not impaired by exposure to ordinary dust. However, even if the statutory dust limit is properly observed, a health hazard cannot be positively ruled out unless it is known with certainty that the dust can have no mutagenic, carcinogenic, fibrogenic, toxic or allergenic effects.

The effects of gypsum dust on human health were first investigated at an early stage of research into pneumoconiosis. Unlike in the case of other activities involving an exposure to dust, such as mine work, the X-rays made of workers from gypsum mines and processing works revealed no evidence either of reactionless retention of dusts in the lungs or of any fibrotic reaction [20]. Both the use of improved X-ray techniques and examinations performed on the lungs of deceased gypsum workers allowed the conclusion to be drawn that inhaled gypsum dust does not produce any morbific effects on the lungs [5, 11]. Animal experiments involving long-term inhalation of gypsum and quartz demonstrated that calcium sulphate is to be regarded as an antagonist to crystalline silicon dioxide [21, 23]. The property of promoting the elimination of quartz from the lungs, the unspecific – inert – dust reaction of the gypsum, and its positive effects on (silico-)tuberculosis led to calcium sulphate dust being used as a so-called "shielding dust" to prevent silicosis. However, this therapeutic use of gypsum dust did not go unchallenged, the main arguments raised against it being the impurities contained in the gypsum, depending on its origin [6, 10, 19]. A more recent clinical study performed on gypsum mineworkers proves that it is only the silicon dioxide content that is responsible for changes to the lungs [18].

A comprehensive study to investigate the mutagenic and carcinogenic properties of calcium sulphate dust was performed at the Institut für Hygiene und Arbeitsmedizin der Rheinisch-Westfälischen Technischen Hochschule, Aachen (Hygiene and Occupational Medicine Institute, RWTH) under *Professor Einbrodt* [2]. This study used FGD gypsum in dust form in animal experiments to clarify the medical aspects of a possible toxic effect on the lungs. The test animals (young female rats) were exposed to a once-only gypsum dust concentration of 25 mg in 0.5 mℓ isotonic sodium chloride solution, applied intratracheally. The animals were examined at intervals of one day, one, three, eight and eighteen months. Histological examination of the lungs revealed signs of an unspecific alveolitis. However, no evidence of granuloma development or enhanced connective tissue formation indicative of incipient pulmonary fibrosis was found in the histological specimens. Parallel chemical analysis by means of flameless atomic absorption spectrometry revealed no elevated presence of aluminium, chromium or nickel in the parenchymatous organs such as the lungs, kidneys or liver. In the early stage of the experiment a build-up of lead in the thighbone was noted, this being washed out after 18 months. The mutagenity tests to Ames made it possible to classify the applied dust as positively non-mutagenic. From these findings the conclusion can be drawn that the gypsum dust used in the experiments can be considered inert.

Like in other highly dust-generating activities, the elevated dust concentrations possible for short times during drilling and sawing of gypsum-based building materials in the application environment make it necessary to take protective actions, e.g. wearing a face mask, even if just for comfort. The dust exposure of the do-it-yourself amateur is to be considered the "worst case" scenario. The amounts of inert calcium sulphate dust that can be inhaled or ingested during the limited time period spent engaged in these activities do not constitute a health hazard.

6.4 Anions and cations

Chemical analyses were performed to determine the anion and cation contents in the gypsum specimens. These components of the gypsum can be of relevance to human health only under certain circumstances in the context of the disposal of gypsum and gypsum-based building materials in landfills. For this reason, this aspect is discussed in the section dealing with the assessment of the health impact of FGD gypsum and natural gypsum products in landfills.

6.5 Trace elements

The production and processing environments

The calculations are based on the statutory dust limit (MAK) of 6 mg/m^3. The concentrations of the individual trace elements are obtained as follows:

max. trace element concentration (µg/m^3) =
dust concentration (mg/m^3) · trace element content (mg/kg) · 10^{-3};

e.g. for arsenic (maximum arsenic content in gypsum = 4 mg/kg):
max. arsenic concentration = $6 \cdot 4 \cdot 10^{-3} = 0.024$ µg/m^3.

Table 10. Comparison of maximum trace element concentrations in gypsum dust (particles suspended in air) in production and processing environments with the maximum allowable concentration (MAK/TRK).

Element	Max. content in natural gypsum (mg/kg)	Max. content in FGD gypsum (mg/kg)	Max. concentration in gypsum dust (µg/m^3)	MAK (µg/m^3)	TRK (µg/m^3)	Max. concentration in gypsum dust corresponds to:
Arsenic	4	3	0.024		100	1/4000 TRK
Beryllium	0.7	0.6	0.004		2	1/500 TRK
Lead	21	22	0.130	100		1/800 MAK
Cadmium*	0.5	0.3	0.003	*	*	*
Chromium	25	10	0.150		100	1/700 TRK
Cobalt	4	2	0.024		100	1/4000 TRK
Copper	14	9	0.084	1000		1/12000 MAK
Manganese	130	200	1.200	500		1/400 MAK
Nickel	13	13	0.078		500	1/6000 TRK
Mercury	0.09	1.3	0.008	100		1/12000 MAK
Selenium	0.5	16	0.096	100		1/1000 MAK
Tellurium	0.2	0.3	0.002	100		1/50000 MAK
Thallium	0.2	0.4	0.002	100		1/50000 MAK
Vanadium	26	8	0.156	50		1/300 MAK
Zinc	40	50	0.300	5000		1/17000 MAK

* No MAK or TRK values have been defined for cadmium

In the production and processing environments, the maximum trace element concentrations are 1/300 to 1/50000 of the respective MAK values. Thus, there is no health hazard due to the intake of copper, lead, manganese, mercury, selenium, tellurium, thallium, vanadium and/or zinc from gypsum dust. The maximum concentrations of the substances thought to be carcinogenic were found to be between 1/500 and 1/6000 of the respective TRK values. Observance of the technological concentration guidelines at the workplace is intended to reduce the health hazard but cannot eliminate it completely. Since, however, the maximum concentrations of the trace elements arsenic, beryllium, chromium, cobalt and nickel in the gypsum dust is three to four orders of magnitude below the respective TRK values, the health risk due to intake of these elements is negligible. No TRK value has yet been defined for cadmium, which is suspected of being carcinogenic. For this reason, the concentration of cadmium in the gypsum dust was compared with the IW 1 exposure limit (0.04 µg/m^3) prescribed in the German clean air regulation (TA Luft) [26], which, however, refers not to workplace concentrations but to concentrations in the atmospheric air. The maximum cadmium concentration in the gypsum dust was only 1/10 of this exposure limit. The health risk due to intake of cadmium is thus likewise negligible (Table 10).

The application environment

The calculations for the application environment were based on the maximum gypsum dust concentration during sawing as determined in the experiments with allowance for the cumulative distribution of the dust and the working practices (5.7). However, the assessment is based not on the trace element concentrations present in the gypsum dust but on the trace element intake during a specific period of time.

The following calculations of the maximum intake of trace elements from gypsum dust are based on the assumption that sawing of gypsum boards and the associated high dust concentration, as described in the worst-case application scenario in 5.7, is a very rare working practice. Accordingly, it is assumed that this kind of work on gypsum boards will be performed twice over a period of ten years, each time involving one sawing session of 1 hour per day and an inhaled volume of 1 m^3/h.

By way of comparison, the trace element intake in clean-air regions and the pollutant intake by a worker under conditions determined by the maximum TRK or MAK concentrations over the same (10-year) period were calculated and used as the basis for the assessment.

Calculation of the volume of clean air inhaled over 10 years, based on an exposure time of 24 hours per day:

inhaled volume: $10\ m^3/24\ h \times 365 \times 10 = 3.6 \times 10^4 m^3$.

Calculation of the volume of air inhaled by a worker based on a 40-hour working week and 45 working weeks per year:

inhaled volume: $10\ m^3/8\ h$; $50\ m^3$/week;
$50\ m^3$/week $\times$ 45 weeks $= 2.25 \times 10^3\ m^3$/year
in 10 years: $2.25\ m^3 \times 103 \times 10 = 2.25 \times 10^4 m^3$

Table 11. Comparison of a maximum trace element intake from gypsum dust (particles suspended in air) in the application environment with the maximum allowable trace element intake of a worker in the production and processing environments at the maximum allowable dust concentration (MAK/TRK) and with the intake from clean air [1, 25].

Element	Max. concentration of element at 100 mg/m³ total dust (µg/m³)	Intake over a period of 10 years: Max. intake in an application environment (µg)	Max. intake by a worker at max. allowable dust concentration (MAK/TRK) (µg)	Intake in clean-air regions (µg)
Arsenic	0.40	0.8	2.25×10^6	365
Beryllium	0.07	0.14	4.50×10^4	*
Lead	2.17	4.34	2.25×10^6	3600
Cadmium	0.05	0.10	**	75
Chromium	2.50	5.0	2.25×10^6	< 365
Cobalt	0.40	0.8	2.25×10^6	365
Copper	1.40	2.8	2.25×10^7	3600
Manganese	20.00	40.0	1.13×10^7	*
Nickel	1.30	2.6	1.13×10^7	600
Mercury	0.13	0.26	2.25×10^6	730
Selenium	1.60	3.2	2.25×10^6	365
Tellurium	0.03	0.06	2.25×10^6	*
Thallium	0.04	0.08	2.25×10^6	*
Vanadium	2.60	5.2	1.13×10^6	*
Zinc	5.00	10.0	1.13×10^6	7300

* Insufficient data available on concentrations of this substance in clean-air regions
** No MAK or TRK values have been defined for cadmium

The intake of the potentially carcinogenic trace elements arsenic, cadmium, chromium and nickel in the application environment lie between 1/100 and 1/1000 of the intake of the same elements in clean air over the assumed period of 10 years. The intake of these elements in the application environment is five to seven orders of magnitude lower than the maximum allowable intake of trace elements at the workplace on the basis of the applicable limits and standards (MAK/TRK). Thus, there is no health hazard due to the intake of trace elements in gypsum dust in an application environment (Table 11).

6.6 Radioactivity

The highest values for radioactivity from natural radioactive substances found in any of the gypsum specimens were:

— potassium 40: 370 Bq/kg

— radium 226: 30 Bq/kg

— thorium 232: 20 Bq/kg

Radium 226 and thorium 232 are significant in terms of the exposure of the occupants to radioactivity. Potassium 40 makes only a minor contribution to the overall radioactivity. The arithmetic mean from about 1000 samples of building materials of various types yielded a radium concentration of 40 Bq/kg and a thorium concentration of 30 Bq/kg [14]. The radionuclide concentration in the natural gypsums and FGD gypsums studied was thus below the average of other building materials. This supports the conclusion that there can be no objections from the radiological point of view to the use of the gypsum-based materials studied in the construction of buildings for residential or other human occupancy purposes.

The man-made radioactive substances cobalt 60, caesium 134 and caesium 137 were not detected in any natural or FGD gypsum specimens.

6.7 Dioxins and furanes

Dioxin ranks among the most highly toxic organic compounds. For this reason, it is a basic requirement that building materials should not give rise to any dioxin exposure in enclosed areas. No dioxins or furanes were detected in any of the natural gypsum and FGD gypsum specimens analyzed, nor in any of the gypsum boards made of natural or FGD gypsum.

6.8 Polycyclic aromatic hydrocarbons

The natural gypsum and FGD gypsum specimens were also analyzed to determine their polycyclic aromatic hydrocarbon content. The most common compound posing a potential health hazard in this group is benzo(a)pyrene. The health implications of these substances derive from the fact that statistical studies have established a probable link between the occurrence of tumours in human beings and frequent contact with mixtures of polycyclic aromatic hydrocarbons in an industrial environment.

No benzo(a)pyrene was detected in any of the gypsum specimens analyzed. Thus, adverse effects on health due to the presence of benzo(a)pyrene in gypsum dust can be positively ruled out.

6.9 Disposal of natural gypsum and FGD gypsum products on landfills

For the purposes of assessing the health impact of the trace elements, in particular of the heavy metals, in gypsum and gypsum-based building materials deposited on landfills via the extent to which they can pollute groundwater and drinking water, Table 12 compares the trace element contents found in gypsum specimens with the statutory limits for allowable concentrations of those elements in the soil [15] and with the concentrations that are accepted as tolerable in cultivated soils [16].

Table 12. Comparison of the trace element concentrations in the gypsum specimens analyzed versus the statutory in-soil concentration limits and with the concentrations frequently found and accepted as tolerable i n cultivated soils.

	Total content of trace elements in gypsum specimens (mg/kg)		Total content of of trace elements in cultivated soils (mg/kg)		
Element	natural gypsum min max	FGD gypsum min max	frequent values	tolerated values	limit values
Arsenic	0.22 – 3.79	0.21 – 2.70	2 – 20	20	
Lead	0.46 – 21.40	0.27 – 22.00	0.1 – 20		100
Cadmium	0.03 – 0.30	0.003 – 0.29	0.1 – 1.0		3
Chromium	0.65 – 24.90	1.02 – 9.72	2 – 50	100	
Fluorine	10 – 60	10 – 70	50 – 200	200	
Nickel	0.3 – 13.40	0.3 – 12.90	2 – 50		50
Mercury	0.006 – 0.05	0.03 – 1.32	0.1 – 1		2

As this comparison shows, the total content of those trace elements that are significant in terms of potential effects of gypsum or gypsum products in landfills on the drinking water is considerably lower, both in natural gypsum and in FGD gypsum, than the generally accepted and tolerated concentrations of those elements in the soil. Nearly all the concentrations measured were within the ranges commonly found in cultivated soils [15, 16].

Thus, pollution of the soil, and thus potentially of the groundwater and drinking water, to above-normal levels by the trace element content, and in particular the heavy metal content, of gypsum and building rubble from products made of natural and FGD gypsum dumped on landfills can be positively ruled out.

The influence of the cations and anions in natural gypsum deposits on the groundwater is known. The major contributing factor is the sulphate, with the result that the groundwater of soils with a high calcium sulphate content may have a relatively high sulphate concentration. For the purposes of assessing drinking water quality [29], separate limits are distinguished for magnesium sulphate and sodium sulphate on the one hand and calcium sulphate on the other. Gypsum is considered unproblematic in this context, on the basis of the findings of various studies that demonstrate that sulphate concentrations of up to 1000 mg/ℓ in the drinking water produce no adverse effects even after many years [3]. For the assessment, it can thus be taken for granted that natural gypsum deposits do not constitute a threat to the drinking water.

No clear distinctions could be found between natural gypsum and FGD gypsum. In all specimens, the concentrations of elutable nitrate were below the allowable concentration of 50 mg/ℓ provided for in the German drinking water ordinance [29]. The concentrations of elutable chloride – for which the drinking water ordinance make no provision – are below the standards given in DIN 2000 (250 mg/ℓ) [9] and in the WHO Guidelines (350 mg/ℓ) [32]. Thus, from the point of view of its health impact, the FGD gypsum analyzed is just as harmless in landfills as is natural gypsum in geological deposits.

7 Conclusions and experts' opinion

7.1 The man-made radioactive substances cobalt 60, caesium 134 and caesium 137 were not detected in any of the natural gypsum or FGD gypsum specimens analyzed. The natural radioactive materials content was very low by comparison with that of other frequently used building materials. The medically significant polycyclic aromatic hydrocarbon benzo(a)pyrene was not detected in any specimen. Dioxins and furanes were not detected either in the natural gypsum specimens or in the FGD gypsum specimen. For this reason, these parameters investigated in the study are no longer considered in the following assessment.

7.2 In the production and processing environments, contact with gypsum occurs via the respiratory tract. The statutory dust limit (maximum workplace concentration, MAK) of 6 mg/m^3 was taken as the maximum exposure concentration, since the inert gypsum dust can be regarded as posing no health hazard. Quantitative analysis for trace elements, in particular heavy metals, showed that the quantities of all elements for which analysis was performed – with the exception of mercury and selenium – in the FGD gypsum specimens were below or in the same order of magnitude as their occurrence in natural gypsum. The mercury and selenium concentrations are considerably higher in the FGD gypsum than in the natural gypsum. In the cases of beryllium and cadmium, the concentrations in the natural gypsum are significantly higher than in the FGD gypsum. The concentrations of all elements are very low, lying below 1/300 of the respective MAK or below 1/500 of the respective TRK values, whichever standard was applicable in each case. Thus a health risk from the production and processing of natural gypsum and FGD gypsum can be positively ruled out.

7.3 In the application environment, where gypsum-based building materials are used in the construction of enclosed living or working areas, no gypsum dust is normally produced, so that a potential exposure can be ruled out. Only in exceptional cases, when work is performed on gypsum-based building materials, in particular by do-it-yourself amateurs, may persons be exposed to gypsum dust for short times. The gypsum dust concentrations occurring in such cases are as a rule below the statutory dust limit (MAK). The trace element concentrations occurring in the gypsum dust are, as demonstrated earlier, very low and can be considered to pose no risk, in particular in view of the short exposure times.

To take into account extraordinary circumstances, too, extremely high dust concentrations were generated such as could arise especially if gypsum boards are inexpertly sawed. These exposures are considered the "worst case" scenario for the do-it-yourself amateur. High gypsum dust concentrations, like high dust concentrations in any other activities, would make it necessary to wear a face mask, even if only for comfort reasons. However, these conditions would apply only very rarely, with the result that the trace element intake over a 10-year period would be less than 1/100 of the pollutant intake from clean air. Thus, there is no health risk in this case, either.

7.4 When gypsum products are disposed of in landfills, their trace element content does not differ significantly from the concentrations normally found in cultivated soils. The trace element concentrations in the natural gypsums and FGD gypsums analyzed are much lower than the applicable statutory limits and the values normally accepted as tolerable for cultivated soils. Otherwise, there is no significant difference in chemical composition between natural gypsum and FGD gypsum, so that the impact of gypsum or gypsum rubble disposed of in landfills on the groundwater is similar to the impact of natural gypsum deposits, deriving only from their sulphate content, which does not pose a health hazard. A further factor to note in this context is that the amounts of gypsum deposited in a landfill will as a rule be much lower than the amounts present in a natural gypsum deposit.

7.5 In **summary**, the analyses demonstrated that the differences between natural gypsum and FGD gypsum in terms of their chemical composition and trace element content are so slight as to be of no relevance to health. The results of the analyses lead to the conclusion that the natural gypsums and FGD gypsums studied can be used without reservation on health grounds in the manufacture of building materials.

Lübeck, 1990

(Professor Dr. med. J. Beckert)
Institut für Hygiene der Medizinischen Universität zu Lübeck

Aachen, 1990

(Professor Dr. med. H.J. Einbrodt)
Institut für Hygiene und Arbeitsmedizin der RWTH Aachen

Berlin, 1990

(Dr. phil. M. Fischer)
(Direktor und Professor am Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes Berlin

8 References

[1] Arbeitsgruppe "Krebsrisiko durch Luftverunreinigungen" des Länderausschusses für Immissionsschutz (LAI): Berichtsentwurf Beurteilungsmaßstäbe für krebserzeugende Luftverunreinigungen vom 28. Januar 1987.

[2] Bartmann, C.: Die biologische Wirkung eines Rauchgasentschwefelungsgipses nach dem Kalksteinverfahren. Diss. Aachen (1986).

[3] Borneff, J.: Hygiene, 4. Aufl. Stuttgart, New York (1982).

[4] Christmann, W., Klöppel, K.-D., Partscht, H., Rotard, W.: "Determination of PCDD, PCDF in Ambient Air". Chemosphere Vol. 19, Nos 1–6, 521–526 (1989).

[5] Cooke, M.A.: Some occupational disease hazards. The older metals and metalloids. J. Industr. News 14, 1213 (1962).

[6] Davis, S.B., Nagelschmidt, G.: A report on the absence of pneumokoniosis among workers in pure limestone. Brit. J. Industr. Med. 13. 6 (1956).

[7] Deutsches Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung. DIN 38406, Teil 1, Weinheim (1988).

[8] DFG Deutsche Forschungsgemeinschaft: Maximale Arbeitsplatzkonzentrationen und Biologische Arbeitsstofftoleranzwerte 1988. Mitteilung XXIV der Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe, Weinheim (1988).

[9] DIN 2000: Leitsätze für die Zentrale Trainkwasserversorgung Berlin (1959).

[10] Doig, A.T.: Disabling pneumoconiosis from limestone dust. Brit. J. Industr. Med. 12, 206 (1955).

[11] Forbes, J.J., Davenport, S.J., Morgis, G.G.: Review of literature on dusts. Bureau of Mines Wash. Bulletin 478, IV, 333 S. (1959).

[12] Gutberlet, H.: Schriftliche Mitteilung (1988).

[13] Hildebrand, M.: Rauchgasentschwefelung bei EVU-Kraftwerken. Energiewirtschaftliche Tagesfragen, Heft 7, 533–539 (1988).

[14] Keller, G., Schmier, H.: Messungen und Untersuchungen über die Radioaktivität von Rauchgas-Entschwefelungs-Anlagen-Gips (REA-Gips) im Vergleich zu Naturgips. Wissenschaft u. Umwelt, 4/1988, 199-201.

[15] Klärschlammverordnung vom 25. Juni 1982. BGBl. I, 734–739.

[16] Kloke, A.: Richtwerte 80. Orientierungsdaten für tolerierbare Gesamtgehalte einiger Elemente in Kulturböden. Mitteilung des Verbandes Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten (VDLUFA), Heft 1–3 (1980).

[17] Mitteilung der VGB Technischen Vereinigung der Grosskraftwerksbetreiber e.V., Essen (1989).

[18] Oakes, D., Douglas, R., Knight, K., Wusteman, M., McDonald, J.C.: Respiratory effects of prolongued exposure to gypsum dust. Am. Occup. Hyg. 26, 838-840 (1982).

[19] Raymond, V., Sivadon, A., Conil, Ph.: Les poumons des carriers et tailleurs de pierre calcaire. Arch. Mal. Prof. 13, 169–178 (1952).

[20] Riddel, G.: Clinical investigations into the effects of gypsum dust. Can. Publ. Hlth. J. 25, 147–150 (1934).

[21] Rosmanith, J. Breining, H.: Die quarzhemmende Wirkung von Naturanhydrit im Tierversuch. Wiss. Umw. (ISU), H. 2 (1988).

[22] Rotard, W.: PCDD/PCDF in Wasser/Sediment und Boden. VDI-Berichte Nr. 631 (1987).

[23] Schepers, G.W.H., Durkan, T.M., Delahunt, A.B.: Effects of inhaled commercial hydrous calcium silicat dust animal tissues. Arch. Industr. Hlth., 348–380 (1955).

[24] Schwarz, O.etzung der Umweltschutzgesetzgebung in der Bundesrepublik Deutschland durch Kraftwerksbetreiber. Sammelband VGB-Konferenz "Kraftwerk und umwelt" (1987).

[25] Schwedt, G.: Ökochemie der Metalle. Umschau, 306, 371, 444 (1984).

[26] TA Luft: Technische Anleitung zur Reinhaltung der Luft vom 27. Februar 1986. GMBl., 95.

[27] TÜV Bayern e.V.: Messung der Staubkonzentration bei der Bearbeitung von Gipskartonplatten aus REA-Gips und aus Naturgips durch Bohren und Schleifen in einem Prüfraum. München, Mai 1988.

[28] Verordnung über Großfeuerungsanlagen. 13. BImSchV, BGBl. I, 719, vom 22. Juni 1983.

[29] Verordnung über Trinkwasser und Wasser für Lebensmittelbetriebe (TrinkwV) vom 22. Mai 1986. BGBl. I 1986, 760.

[30] Volkart, K.: Bauen mit Gips, 11. Aufl., Darmstadt (1986).

[31] Volkart, K.: REA-Gips ist Calciumsulfat-Dihydrat. Bauwirtschaft 42, 636/637 (1988).

[32] WHO: Guidelines for Drinking Water Quality. World Health Organisation (1984).

[33] Wirsching, F.: Chemische Technologie, Bd. 3 (Gips). München, Wien (1983).

[34] World Mineral, Statistics 1980–1984. Keyworth, Nottinghamshire (1986).